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Manuscript Report No. 87-13

The Bait Fishery of the Lower Red River

By Lysack, W., 1987

Manitoba
Natural Resources
Fisheries

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The bait fishery of the lower Red River.

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TABLE OF CONTENTS

	Page
INTRODUCTION	1
METHODS	4
RESULTS	13
DISCUSSION	101
ACKNOWLEDGMENTS	107
REFERENCES	109

INTRODUCTION

The Red River drains the southern reaches of the lakebed which was once covered by the glacial Lake Agassiz. From its headwaters in Minnesota, U.S.A., it drains 287,500 km^2 of sedimentary rock covered with glacial Lake Agassiz sediments. The Red River watershed is used for intensive agriculture (primarily the production of cereal crops and livestock) and also contains several urban areas. A major tributary, the Assiniboine River, flows southeasterly from central Saskatchewan to the confluence in the City of Winnipeg. From there the Red River flows northward through the vast Netley Marshes and empties into Lake Winnipeg's southern basin. The hydrological regime of the Red River is described in detail by Brunskill et al. (1980).

Recent modifications to the lower reaches of the Red River include the construction of the Lockport dam in the early 1920's and the Red River floodway which was completed in 1967. Upstream movements of fishes are restricted by the Lockport dam. Some upstream movement occurs through the boat locks and a fish ladder during the open water season.

The International Garrison Diversion Study Board (1976) reported that 89 species of fish occur in the Red River basin and 66 of these species occur in the Manitoban stretch. Clarke et al. (1980) captured 35 fish species with a variety of gear types. The emerald shiner, Notropis atherinoides, comprised 98% of seine catches reported by Clarke et al. (1980) and 97% of seine catches reported by Derksen and Howard (unpublished report, Manitoba Dept. of Natural Resources) in 1974.

Other cyprinids and small fishes caught by Clarke et al (1980) include chestnut lampreys, Ichthyomyzon castaneus, one silver lamprey, I. unicuspis, lake chub, Couesius plumbeus, silver chub, Hybopsis storeriana, one hornyhead chub, Nocomis biguttatus, river shiners, Notropis blennius, spottail shiners, N. hudsonius, fathead minnows, Pimephales promelas, longnose dace, Rhinichthys cataractae, stonecats, Noturus flavus, tadpole madtoms, N. gyrinus, trout perch, Percopsis omiscomaycus, johnny darters, Etheostoma nigrum, yellow perch, Perca flavescens and river darters, Percina shumardi.

The Red River below the Lockport dam is the most heavily angled area in Manitoba. In 1982, about 337,000 angler-hours were exerted to harvest about 113,000 kg of fish. Anglers catches were dominated by freshwater drum, Aplodinotus grunniens, saugers, Stizostedion canadense, goldeyes, Hiodon alosoides and walleyes, Stizostedion vitreum (Lysack 1986).

The lower reaches of the Red River also support a viable bait fishing industry. Derksen and Howard (1974, unpublished report, Manitoba Dept. of Natural Resources) reported that 75% of the total Manitoban bait fish yield originated from the Red River. The gross value of the Red River bait fish yield was about $250,000. These catches are comprised exclusively of emerald shiners which are frozen and sold in small plastic tubs to anglers. Since 1983, a moratorium on the sale of live bait fish has been in existence.

This study was initiated in 1983 in response to a demand to collect and analyse bait fishery data to be used in devising bait fishery management policies. The objectives of this study were to:

1. describe the characteristics of bait fishing operations on the Red River

2. quantify commercial yields and fishing effort

3. compare commercial catches of side rig and front rig boats

4. quantify spatial and temporal changes in emerald shiner abundance in a variety of riverine habitats

5. examine the usefulness of length frequency distributions in determining the age composition of the emerald shiner popuation

6. describe the growth regimes of emerald shiners

7. describe the fecundity and maturity regimes of emerald shiners

8. describe and evaluate sources of sampling bias

This study was performed during the open water seasons of 1983 and 1984. Sampling was confined to four areas downstream from the Lockport dam.

METHODS

Due to financial and temporal restraints, only four sampling areas were chosen (Fig. 1). Area 1 was chosen to represent the river proper, area 2 was chosen to represent the river as affected by small tributaries draining southern areas of the marshes, area 3 was chosen to represent the interactive effects of Lake Winnipeg and the marshes and area 4 was chosen to represent Lake Winnipeg's effects.

Three types of habitat were sampled within each riverine sampling area. Unvegetated and vegetated habitats along the shores were sampled. The third type of sampled habitat was located in the midstream zone of each area. Three samples were collected from each type of habitat in each riverine sampling area. Only three samples were collected from the fourth area since the riverine habitat classifications did not apply in the lake situation.

Biweekly samples were collected from each area during the open water seasons of 1983 and 1984. Sampling period numbers and dates for 1983 and 1984 are as follows:

Period No.	Dates	
	1983	1984
1		May 20 - June 2
2		June 3 - 16
3		June 17- 30
4	July 3 - 16	July 1 - 14
5	July 17- 30	July 15- 28
6	July 31- Aug. 13	July 29- Aug. 11
7	Aug. 14- 27	Aug. 12- 25
8	Aug. 28- Sept. 10	Aug. 26- Sept. 8
9	Sept.11- 24	Sept. 9- 22
10	Sept.25- Oct. 8	Sept.23- Oct. 6

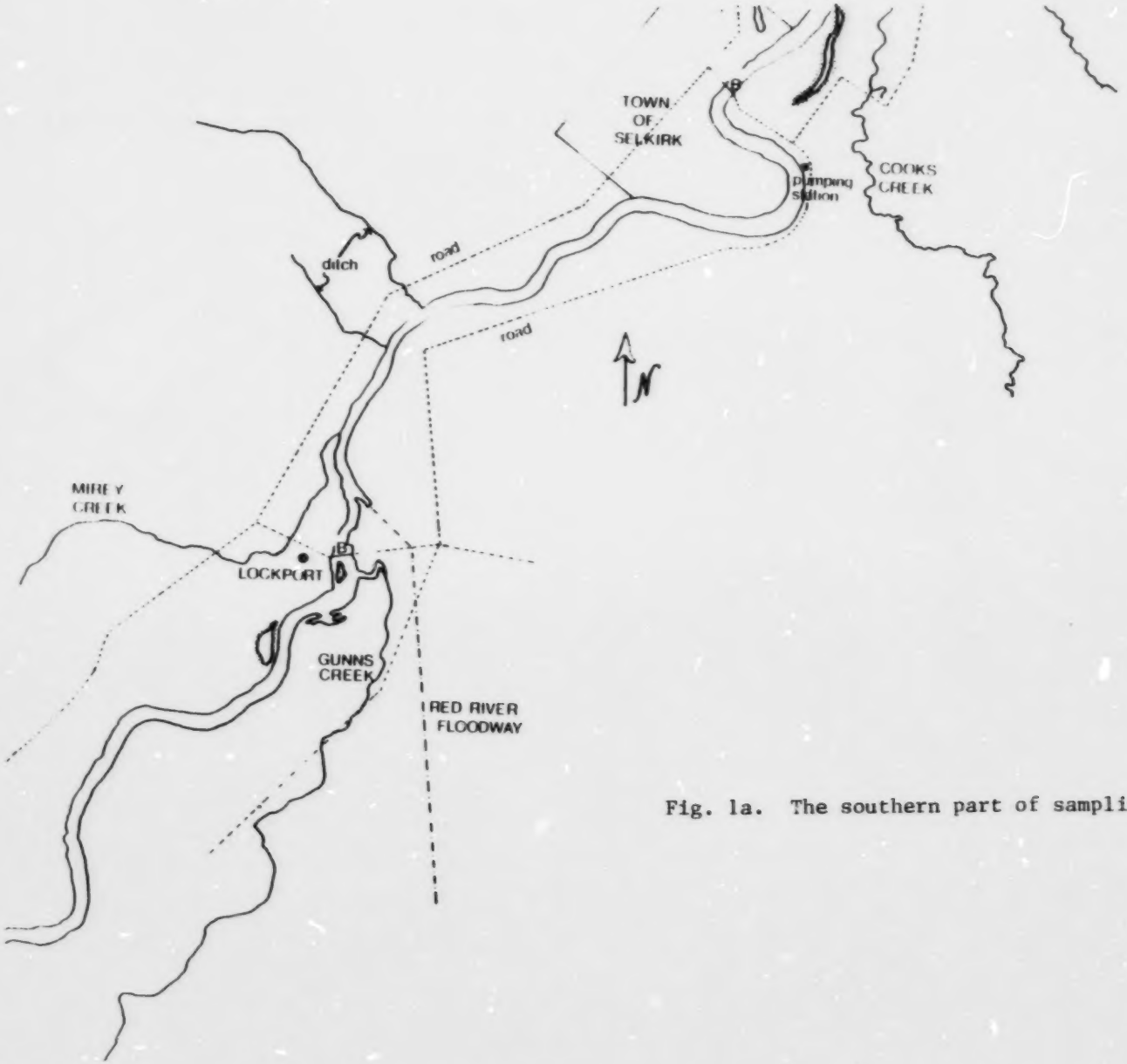

Fig. 1a. The southern part of sampling area 1.

Fig. 1b. The northern part of sampling area 1.

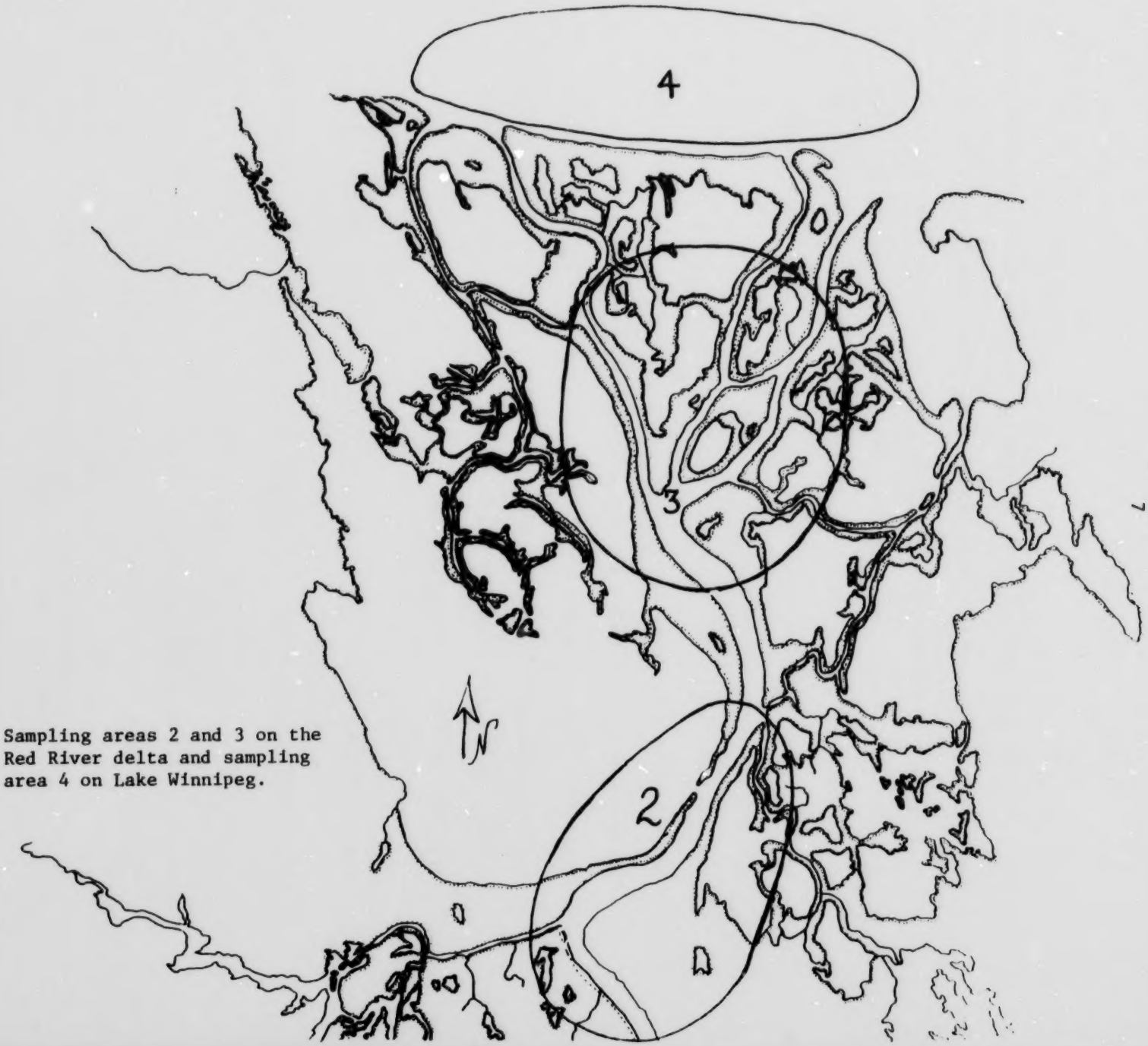

Fig. 1c. Sampling areas 2 and 3 on the Red River delta and sampling area 4 on Lake Winnipeg.

Spatial and temporal changes in emerald shiner abundances were monitored exclusively with tandem meter nets towed behind the bow of a 22 foot long motor boat. Each net had an 18 inch diameter mouth and was 8 feet long. The mouth was held open by two stainless steel hoops sewn into the net at a 2 foot interval. The posterior part of the net was conical and terminated in a plastic collection bucket. The meter net was composed of 0.25 inch square nylon mesh. While in use, the nets were held horizontally with a 3 point towing bridle and dorsally suspended metal wing depressors. One of the nets was outfitted with a digital flowmeter (General Oceanics Inc., 1295 N.W. 163rd St., Miami, Florida, 33169, U.S.A.) attached with 2 thin nylon bridles so that the flowmeter was suspended at the center of the net mouth. The volume of water sampled during each tow was calculated according to the following formulae:

$$\text{sampled volume } (m^3) = \frac{\pi \cdot (\text{diameter}(m))^2}{4} \cdot \text{towing distance } (m)$$

$$\text{where towing distance } (m) = \frac{\text{difference in flowmeter counts} \cdot \text{rotor constant}}{999999}$$

$$\text{and rotor constant} = 26873$$

After a series of trial tows performed in June, 1983, a standard tow duration of 4 minutes was chosen for the following reasons:

1. tow durations less than 4 minutes in midstream habitats caught no fish
2. tow durations greater than 4 minutes in vegetated habitats caught too many fish and too much debris so that sampling efficiency was reduced

3. tow durations greater than 4 minutes in most of the vegetated areas overran the area and would terminate in another type of habitat

4. Many tow durations greater than 4 minutes caught fewer fish than tows of shorter durations, implying that sampling efficiency decreased with increasing tow durations

All fish caught by both nets during one standard tow were combined into a single sample which was stored in a frozen state. Water temperatures were recorded during each sampling day.

The total number of fish and the total weight of fish (± 5 mg, Sartorius electronic balance, model 1402 MP7-2) from each thawed sample were determined.

Various numbers of fish were "randomly" selected from samples collected during each biweekly sampling period. Individual body (fork) lengths of these fish were measured to the nearest millimeter. These lengths were used to develop length frequency distributions for each biweekly period.

In 1983, various numbers of fish were "randomly" selected from samples collected during each biweekly sampling period. Individual body lengths (± 1 mm) and corresponding body weights (± 5mg) were determined. These data were used to develop length-weights relationships.

In 1984, twenty one emerald shiner females ranging from 60 to 87 mm in fork length were selected from samples collected during period 3. The length (± 1 mm) and weight (± 5 mg) of each fish was determined. Ovaries from each female were removed and stored in Gilson's fluid (Bagenal 1968) for a minimum of 4 weeks. Connective tissue was removed by water washes and the eggs were preserved in a 10% solution of formalin. The total number of eggs from each female was determined using stereomicroscope at 40X.

In 1984, 1052 emerald shiners collected during sampling periods 1 - 5, were examined in an attempt to determine each fish's sex and state of maturity.

In 1983, eight commercial bait fishermen provided the following information each week from May to September: number of days spent fishing daily and (or) weekly catch and fishing zone. The four commercial bait fishery zones are depicted in Figure 2. Commercial bait fishermen reported their catches in terms of "tubs". These tubs are lidded plastic containers that each hold about 100 emerald shiners (200 gm). All bait fishermen on the Red River use a standard sized tub for packaging and freezing their catch. Some of the fishermen tow pliable trawl nets from the sides of their boats ("side rigs") while others push a framed, rigid net attached to the bows of their boats ("crazy house" or "front rig"). Twenty one tubs of emerald shiners were purchased from commercial fishermen using side rigs and front rigs during the summer of 1983. The number and total weight of fish in each tub were determined. Individual lengths and weights of commercially caught shiners were used to construct length frequency histograms for fish caught by each gear type.

Scales and otoliths were removed from subsamples of varying sizes from our tow samples and from the commercial samples. Whole otoliths and scales were examined at 40 - 72X under a stereomicroscope in an attempt to determine the fish's age.

Tow catches were standardized by calculating densities of emerald shiners per cubic meter of sampled water in terms of numbers and total weights. Routine statistical analyses were performed according to Snedecor and Cochran (1967). Geometric mean functional (GMF) regression

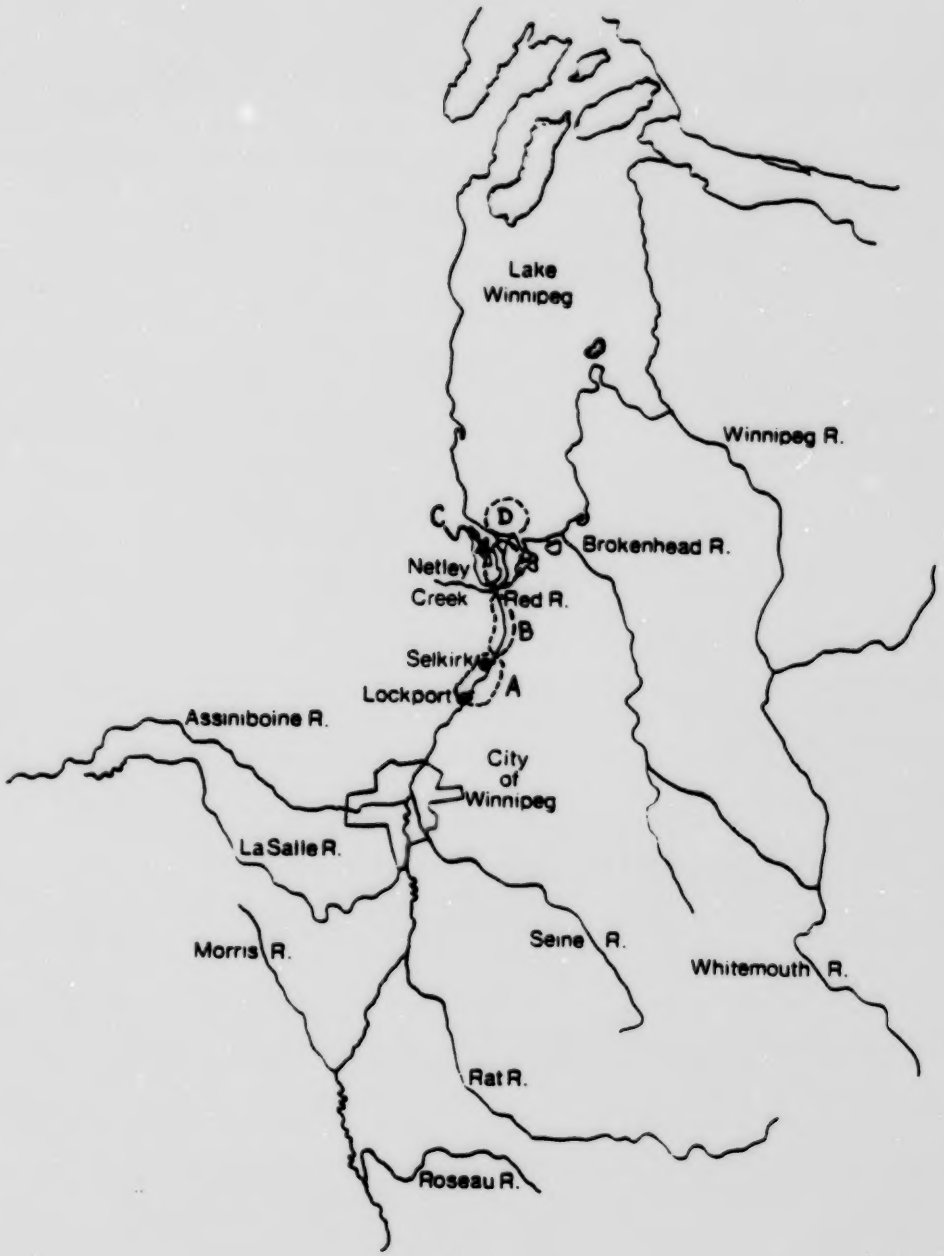

Fig. 2. A, B, C and D denote the four sampled commercial bait fishing zones.

analyses were performed according to Ricker (1975). Some of the length frequency histograms were smoothed using a three point moving average. Confidence intervals about the slope, $\hat{\beta}_1$, and intercept, $\hat{\beta}_o$, of fitted regression lines were calculated as follows:

$$C.I.\ (\hat{\beta}_1) = \pm\ t_{\alpha/2}\ S.E.\ (\hat{\beta}_1)$$

$$C.I.\ (\hat{\beta}_o) = \pm\ t_{\alpha/2}\ S\sqrt{\frac{1}{n} + \frac{\bar{x}^2}{SS(x)}}$$

where S= standard deviation

A "confidence ellipse" about a point($\hat{\beta}_o$(abscissa), $\hat{\beta}_1$(ordinate)) was plotted according to:

$$y = \hat{\beta}_1 + \sqrt{C.I.(\hat{\beta}_1) - \frac{C.I.(\hat{\beta}_1)^2 (x-\hat{\beta}_o)^2}{C.I.(\hat{\beta}_o)^2}}$$

RESULTS

Spatial and temporal changes in numerical densities of emerald shiner juveniles and adults determined by standard tows are depicted in Figs. 3 - 15. For each river area, a series of four figures depicts density changes in vegetated, unvegetated and midstream habitats while the last figure depicts density changes in that area irrespective of habitat types.

The same spatial and temporal changes as described above are depicted in terms of weight densities in Figs. 16 - 28. The top panel represents 1983 data and the bottom panel represents 1984 data in each of these figures.

Inordinately large values of standard deviations about each point in Figs. 3 - 28 were truncated. Each point represents the mean of three replicate samples. All data are recorded in appendices A - D.

A one-way analysis of variance (1 way ANOVA) examining the effects of habitat types, river areas, sampling periods and replicates on volumes of water sampled by the tow nets in areas 1 - 3 during 1983 indicates that sampled volumes varied significantly among habitat types and among periods. River areas and replicates had no effect on sampled volumes (Appendix E). Volumes sampled in the midstream habitats were larger than those in shoreline habitats. Volumes varied erratically among periods. A two way (randomized complete block with replication) ANOVA indicated the following significant (P=0.05) effects in 1983:

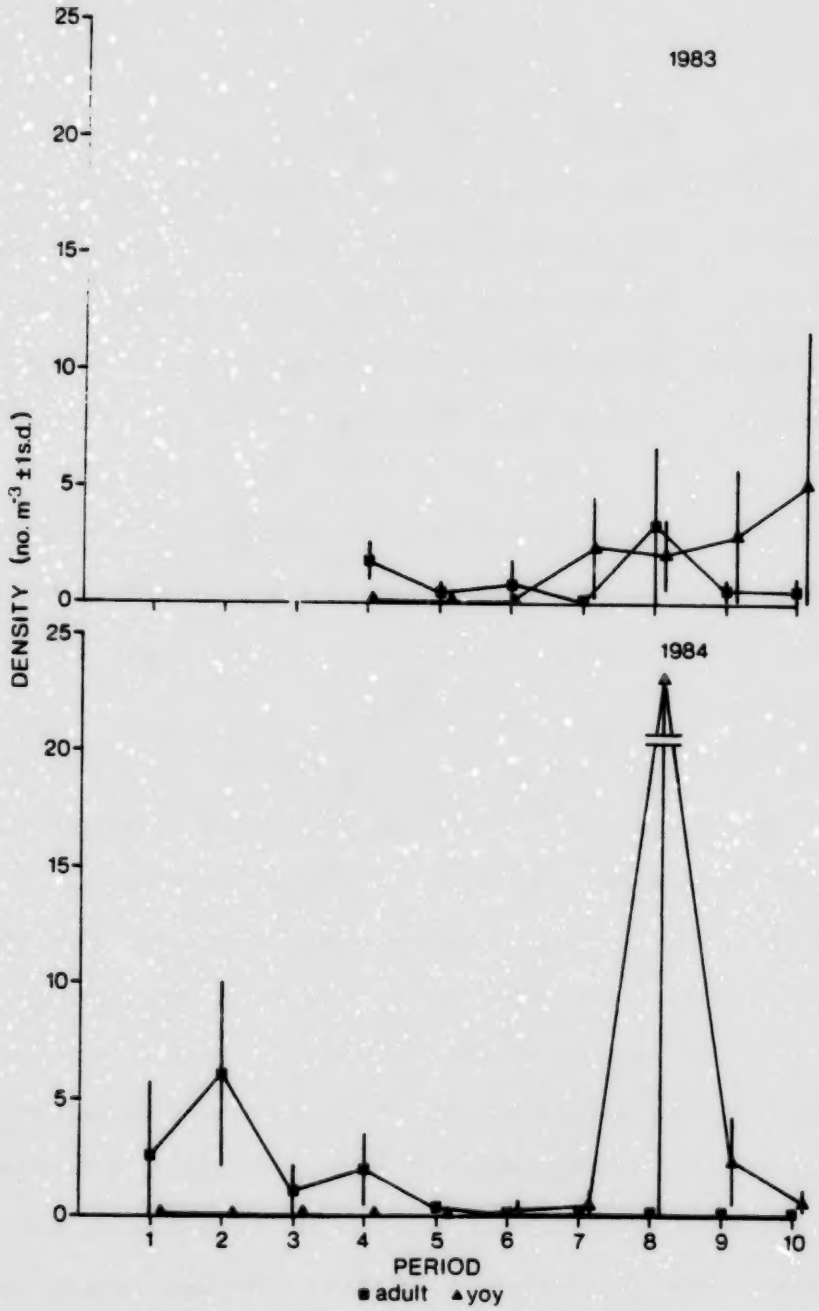

Fig. 3. Temporal changes in emerald shiner densities sampled from the vegetated zone of area 1 of the Red River.

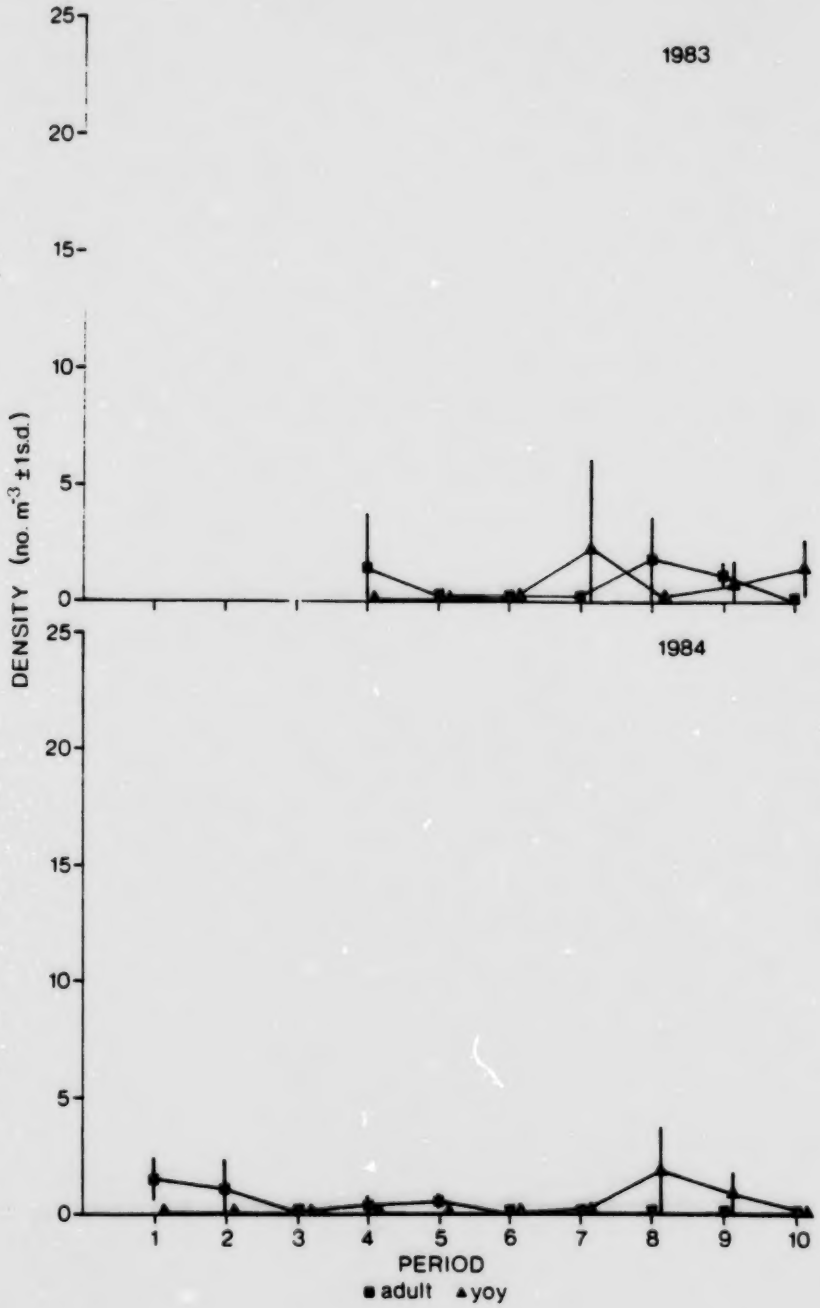

Fig. 4. Temporal changes in emerald shiner densities sampled from the unvegetated zone of area 1 of the Red River.

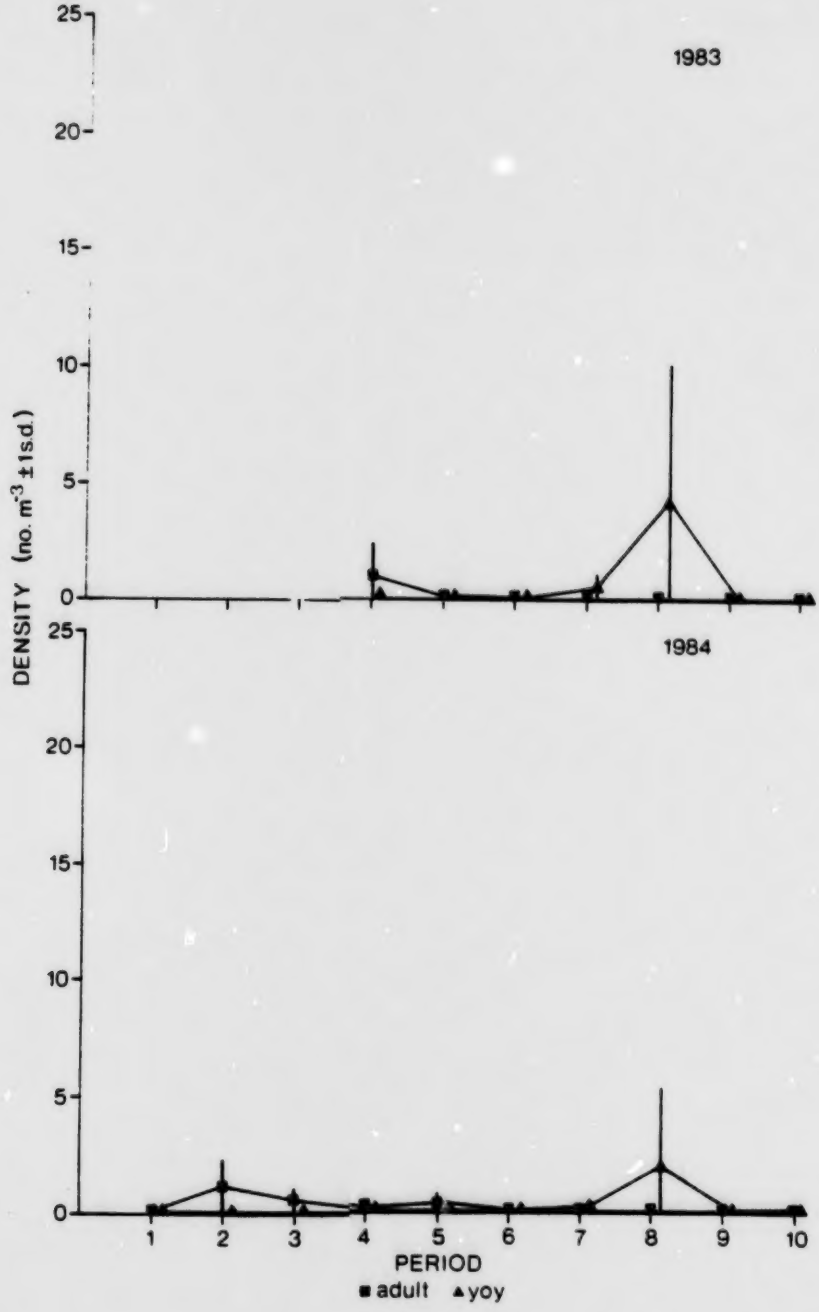

Fig. 5. Temporal changes in emerald shiner densities sampled from the midstream zone of area 1 of the Red River.

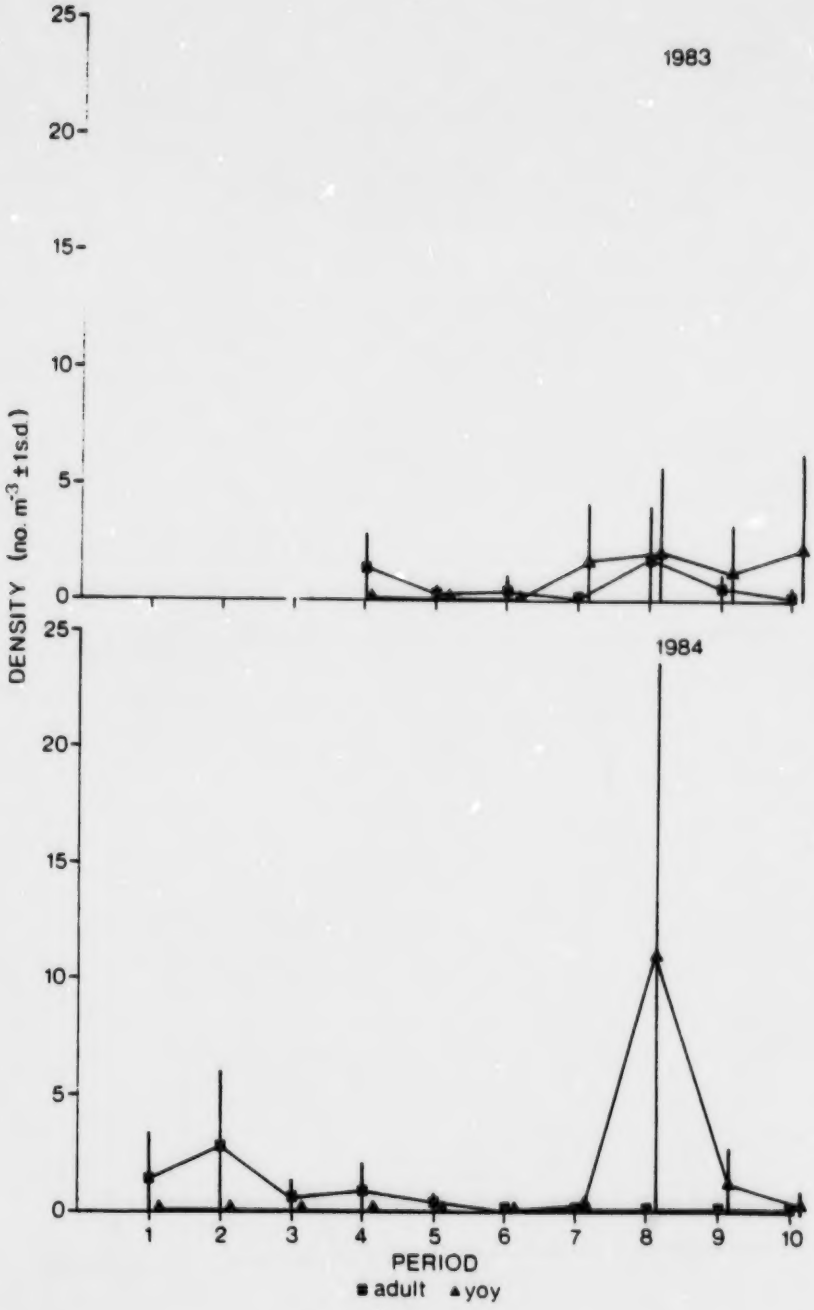

Fig. 6. Temporal changes in pooled densities of emerald shiners sampled from area 1 of the Red River.

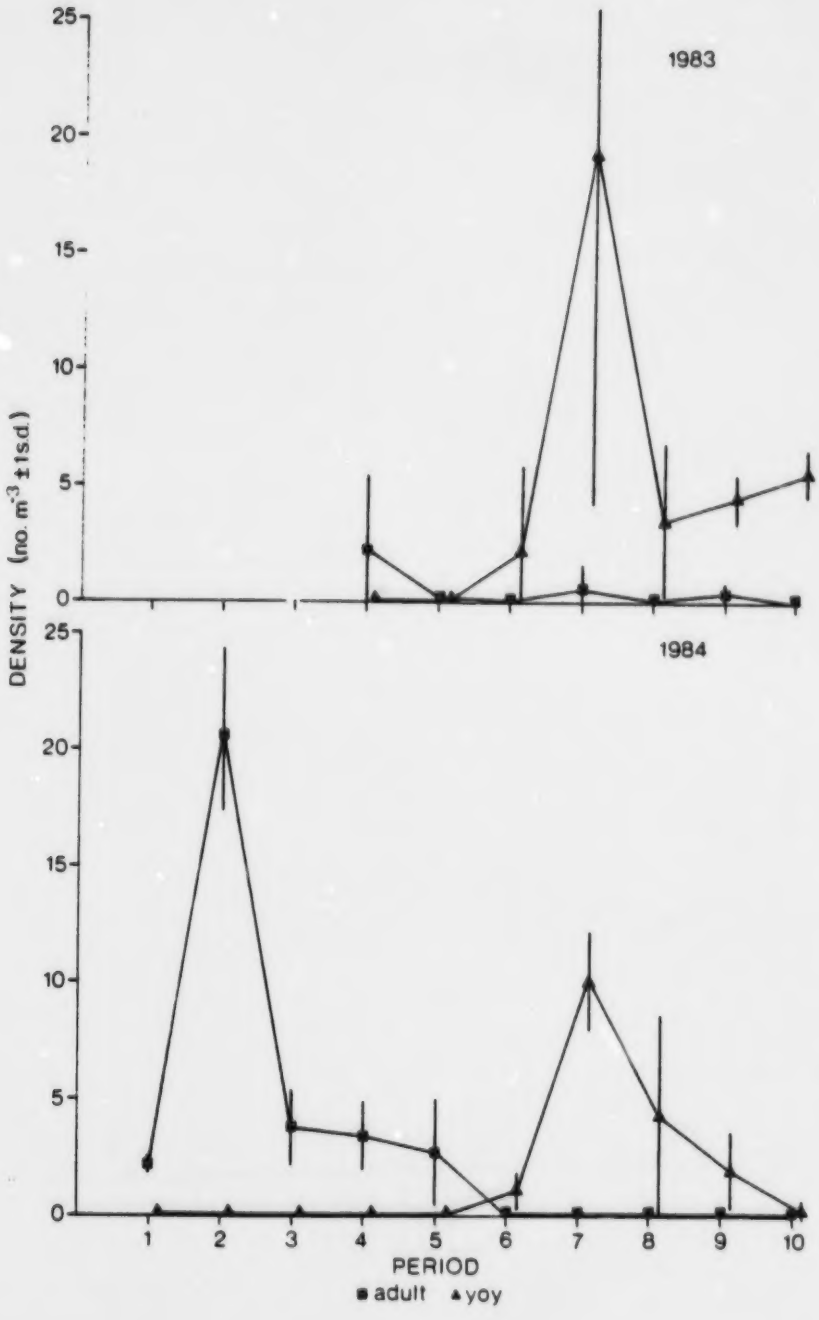

Fig. 7. Temporal changes in emerald shiner densities sampled from the vegetated zone of area 2 of the Red River.

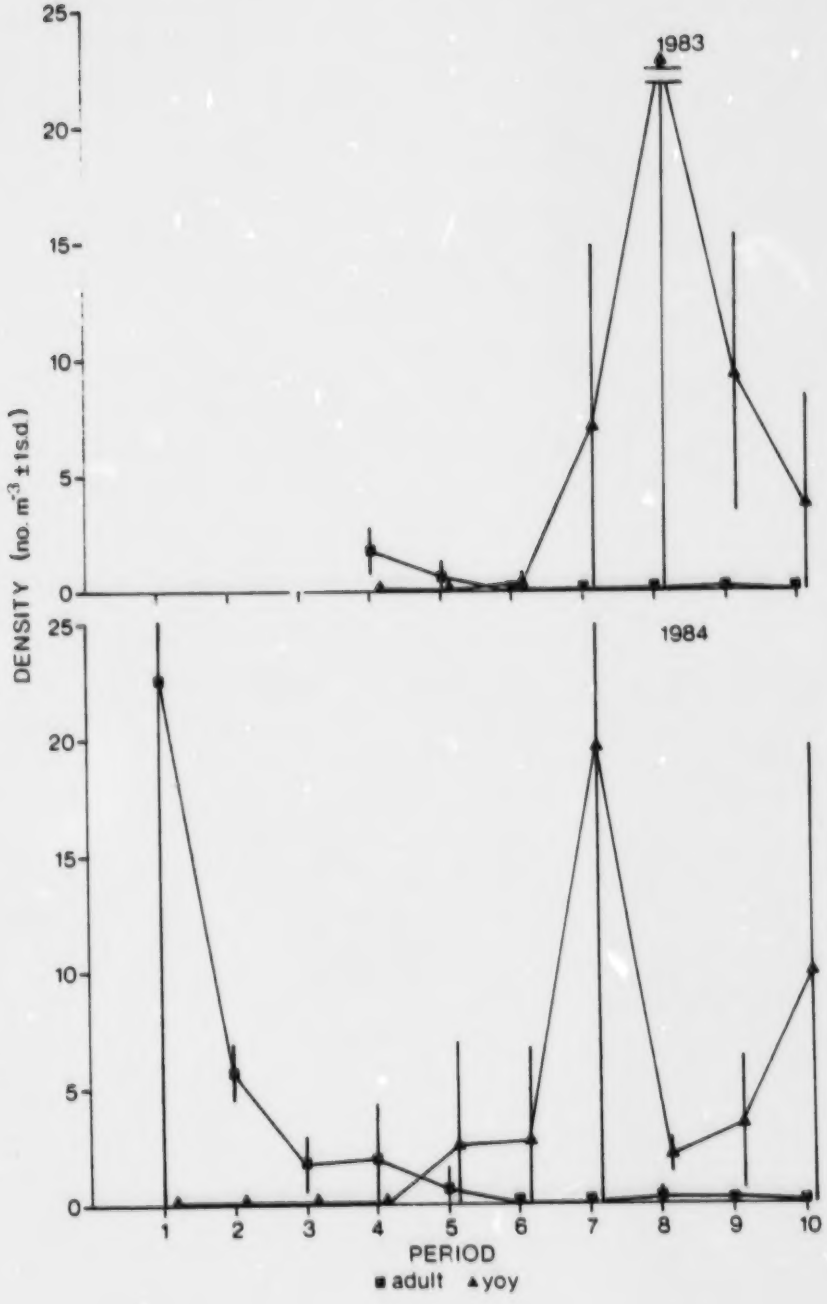

Fig. 8. Temporal changes in emerald shiner densities sampled from the unvegetated zone of area 2 of the Red River.

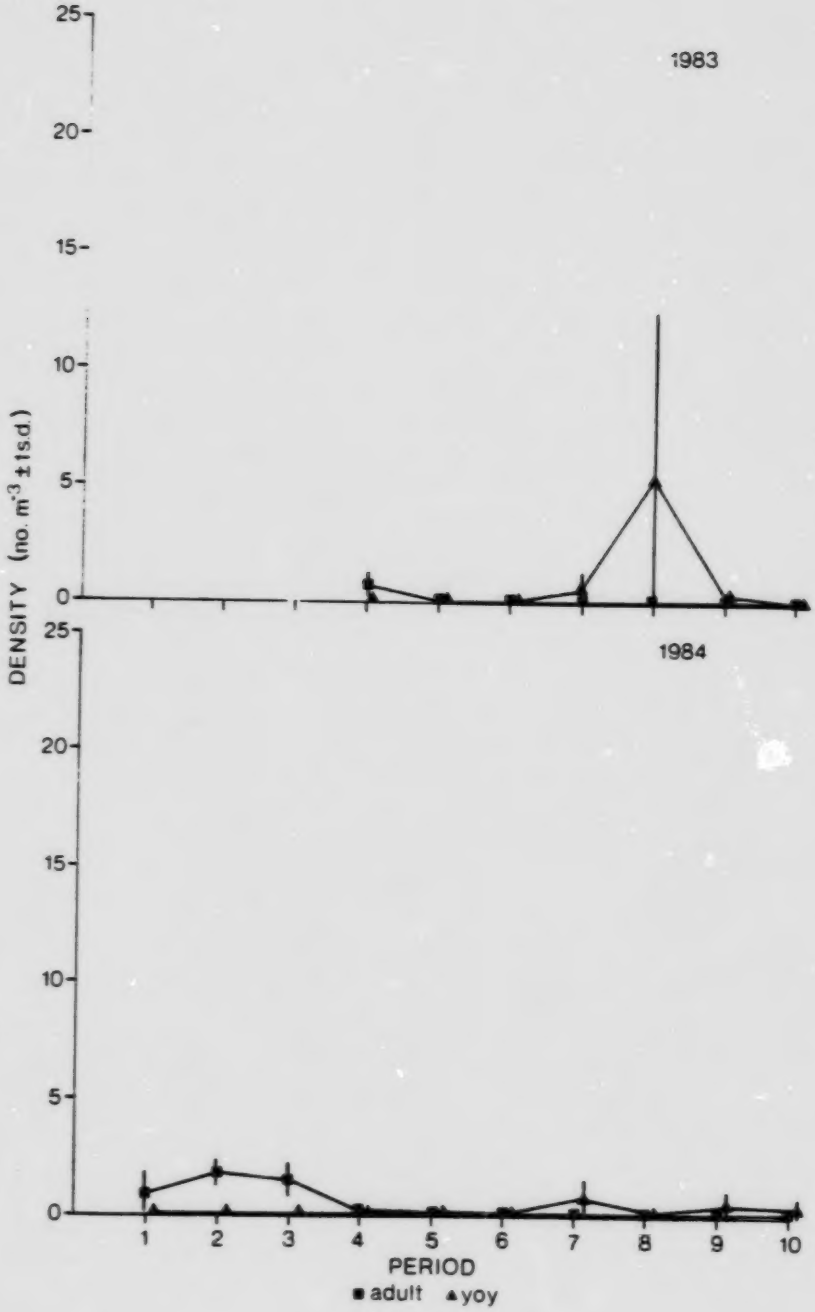

Fig. 9. Temporal changes in emerald shiner densities sampled from the midstream zone of area 2 of the Red River.

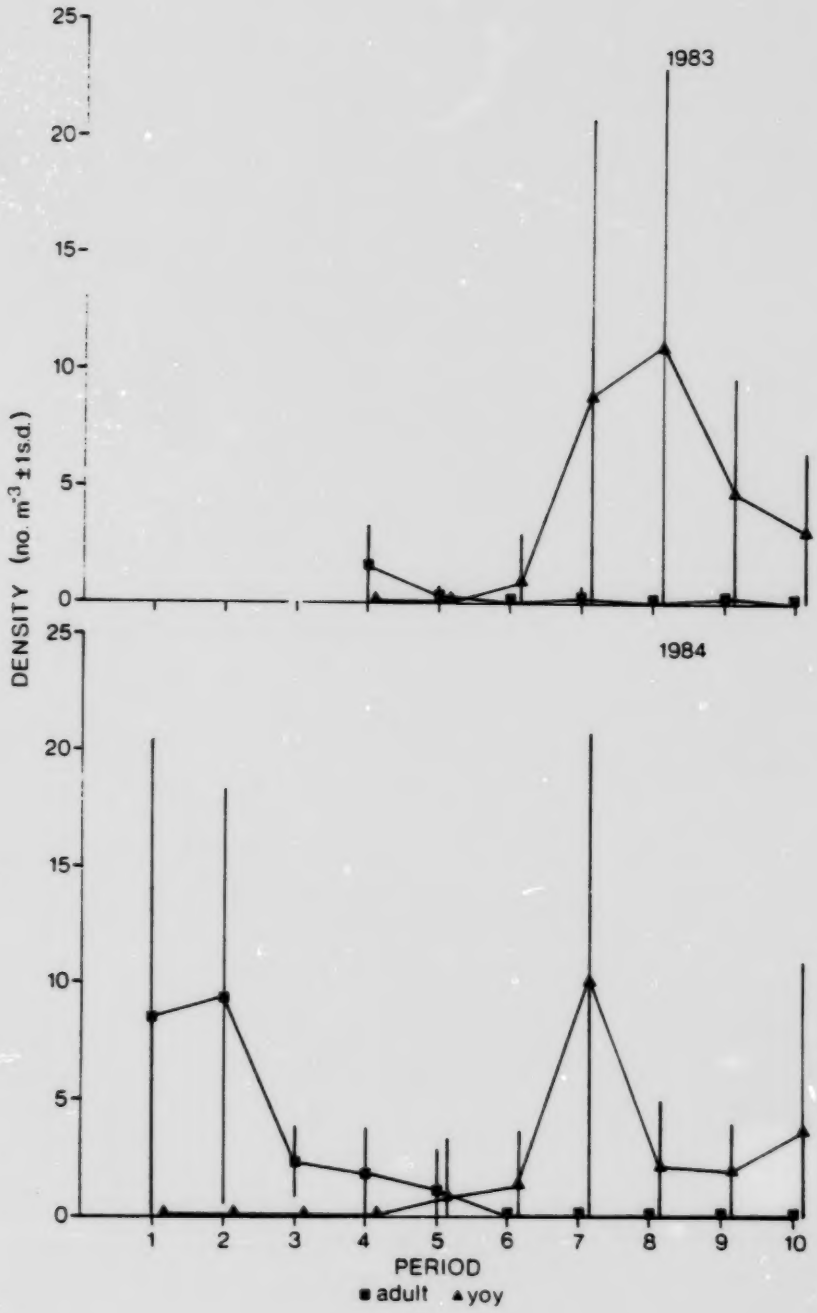

Fig. 10. Temporal changes in pooled densities of emerald shiners sampled from area 2 of the Red River.

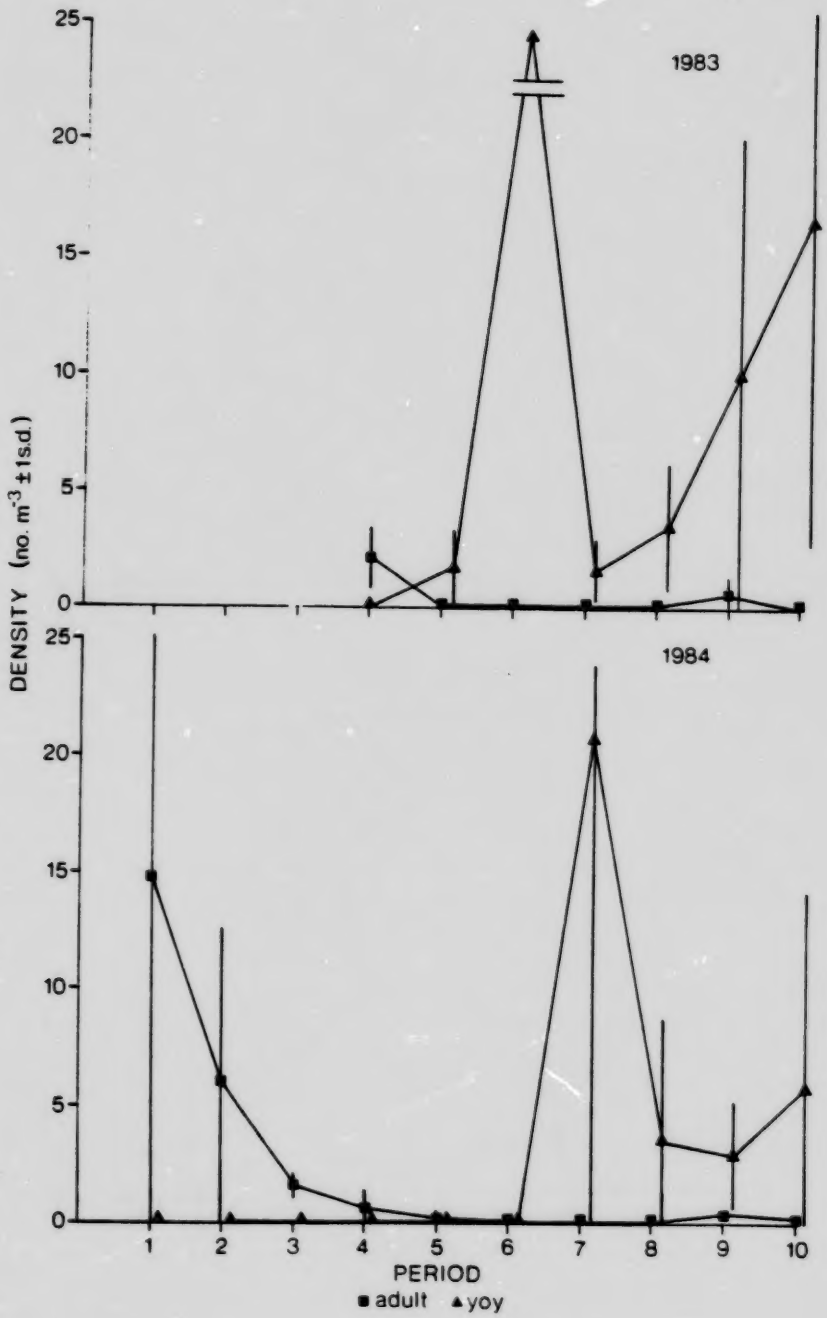

Fig. 11. Temporal changes in emerald shiner densities sampled from the vegetated zone of area 3 of the Red River.

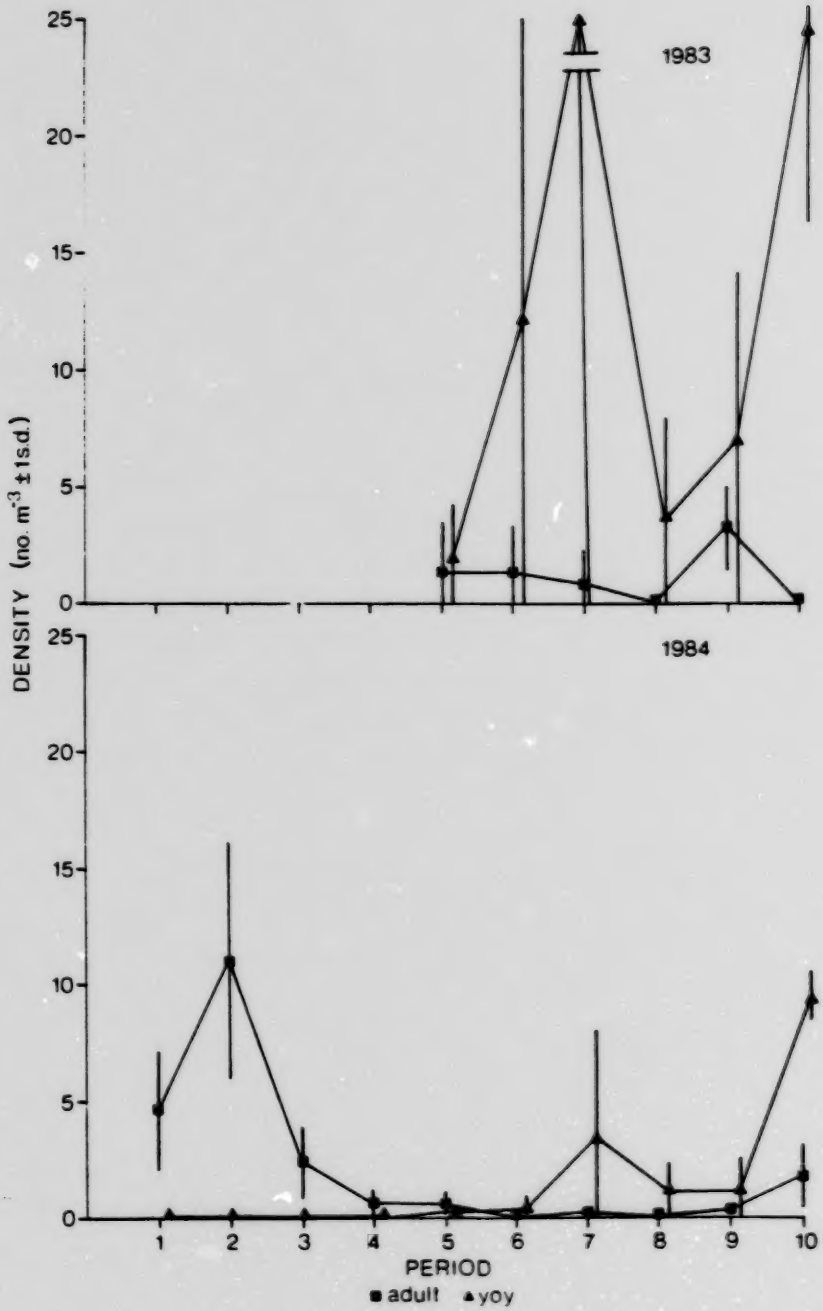

Fig. 12. Temporal changes in emerald shiner densities sampled from the unvegetated zone of area 3 of the Red River.

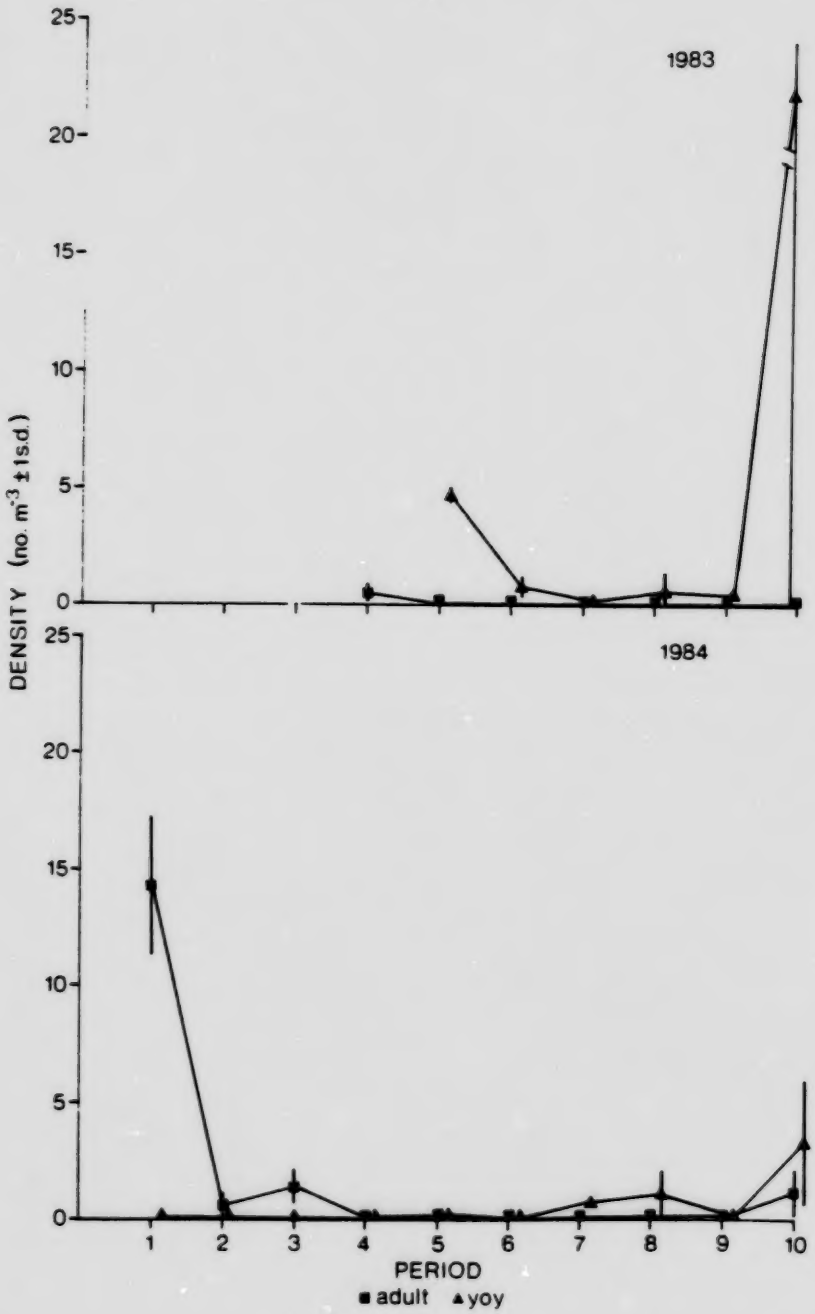

Fig. 13. Temporal changes in emerald shiner densities sampled from the midstream zone of area 3 of the Red River.

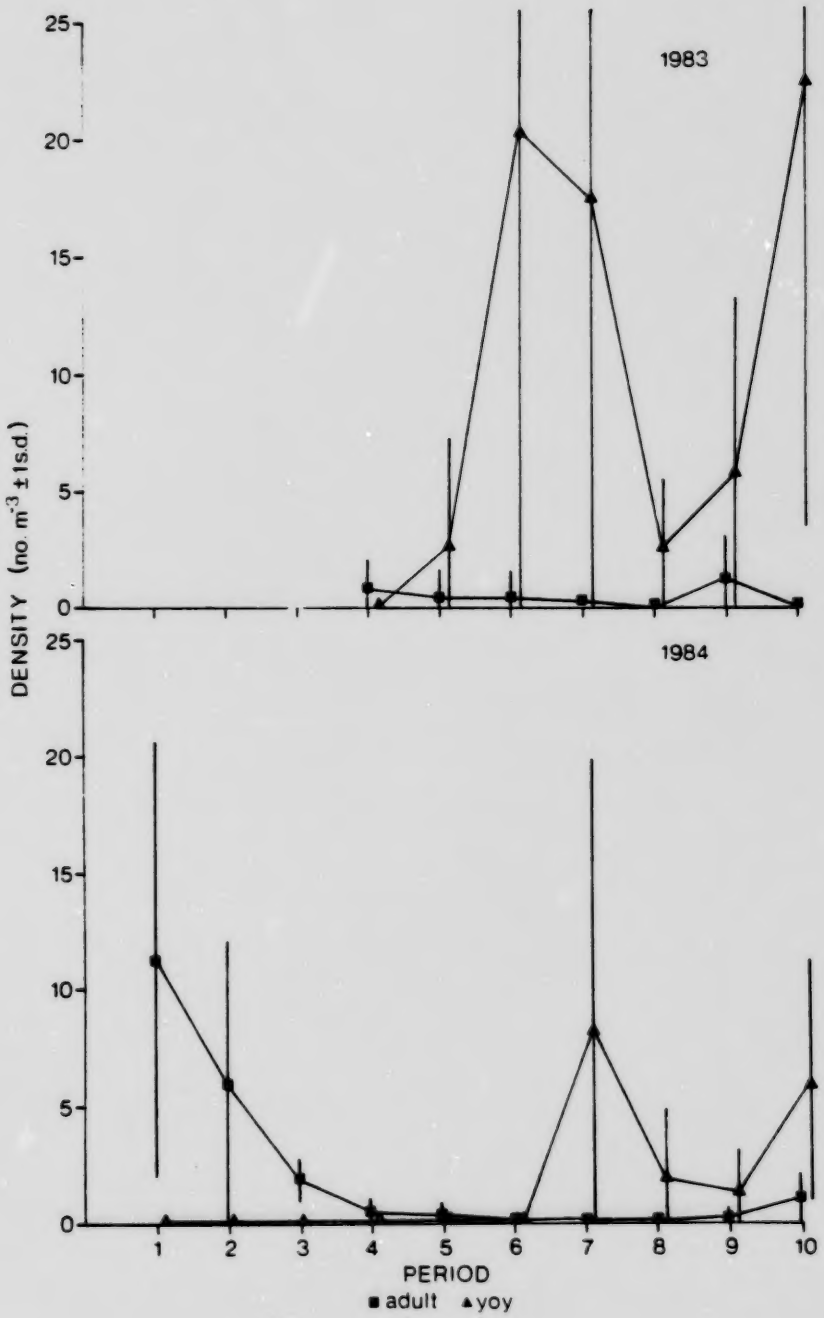

Fig. 14. Temporal changes in pooled densities of emerald shiners sampled from area 3 of the Red River.

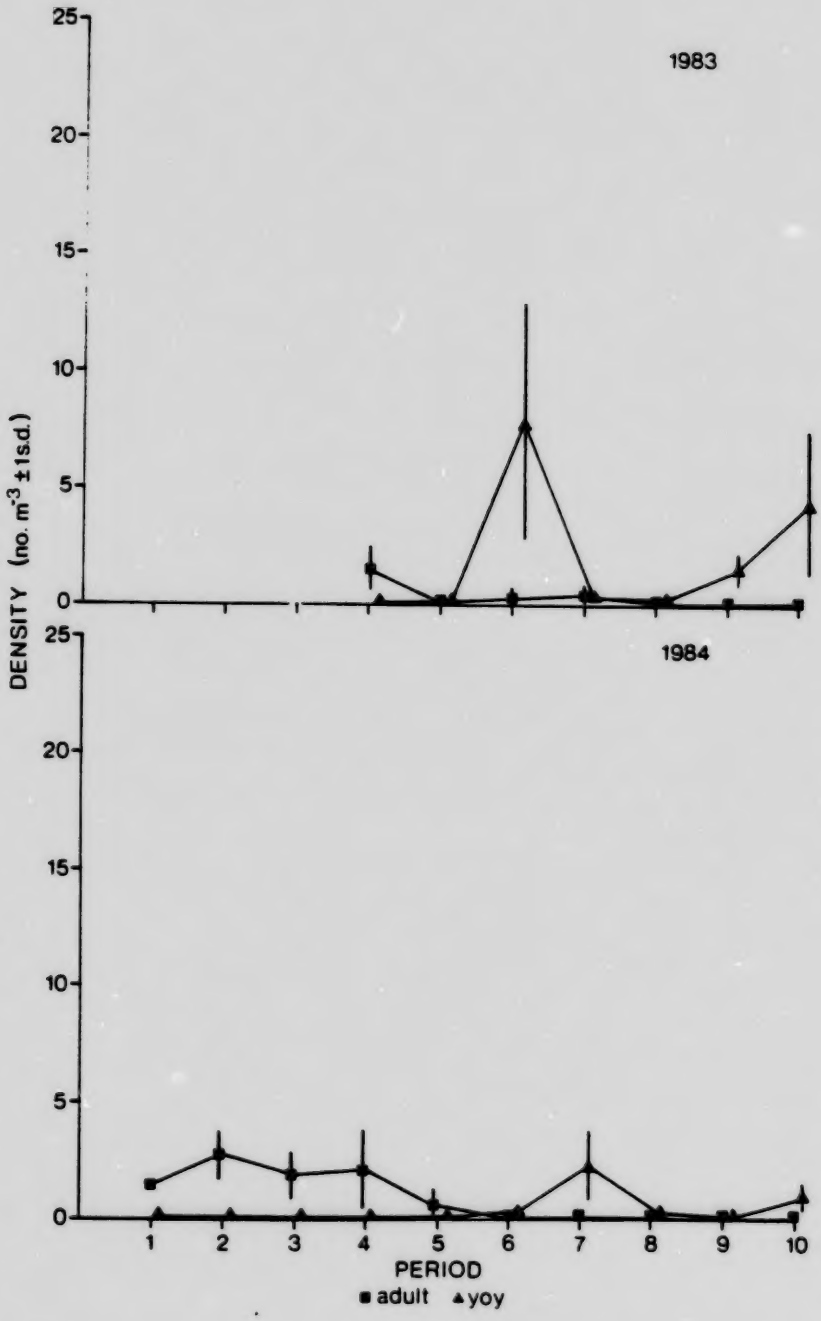

Fig. 15. Temporal changes in emerald shiner densities sampled from Lake Winnipeg.

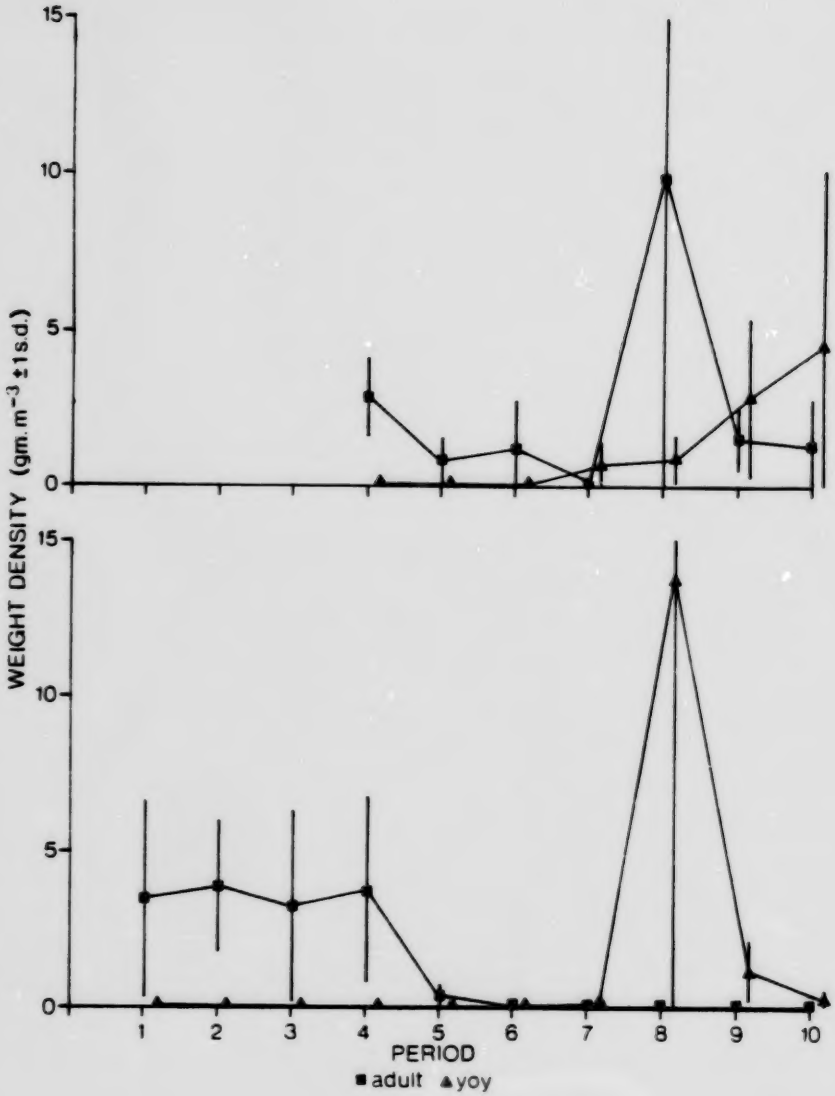

Fig. 16. Temporal changes in weight densities of emerald shiners sampled from the vegetated zone of area 1 of the Red River.

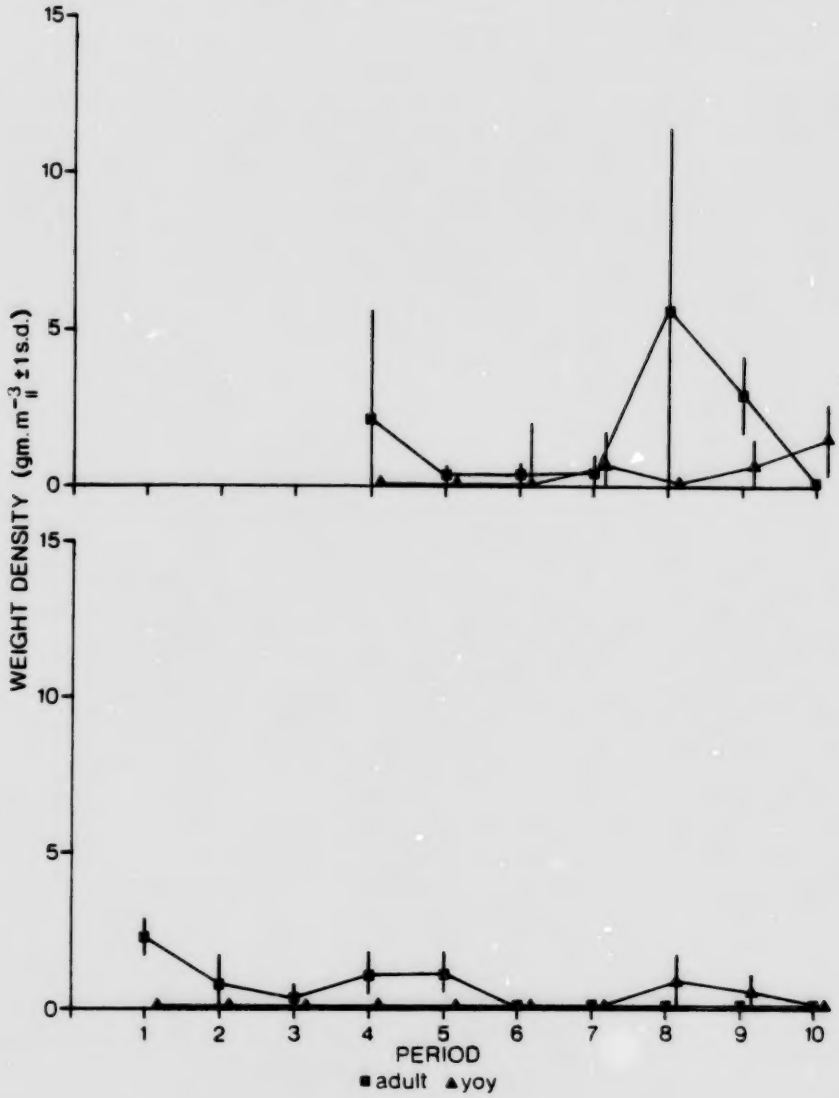

Fig. 17. Temporal changes in weight densities of emerald shiners sampled from the unvegetated zone of area 1 of the Red River.

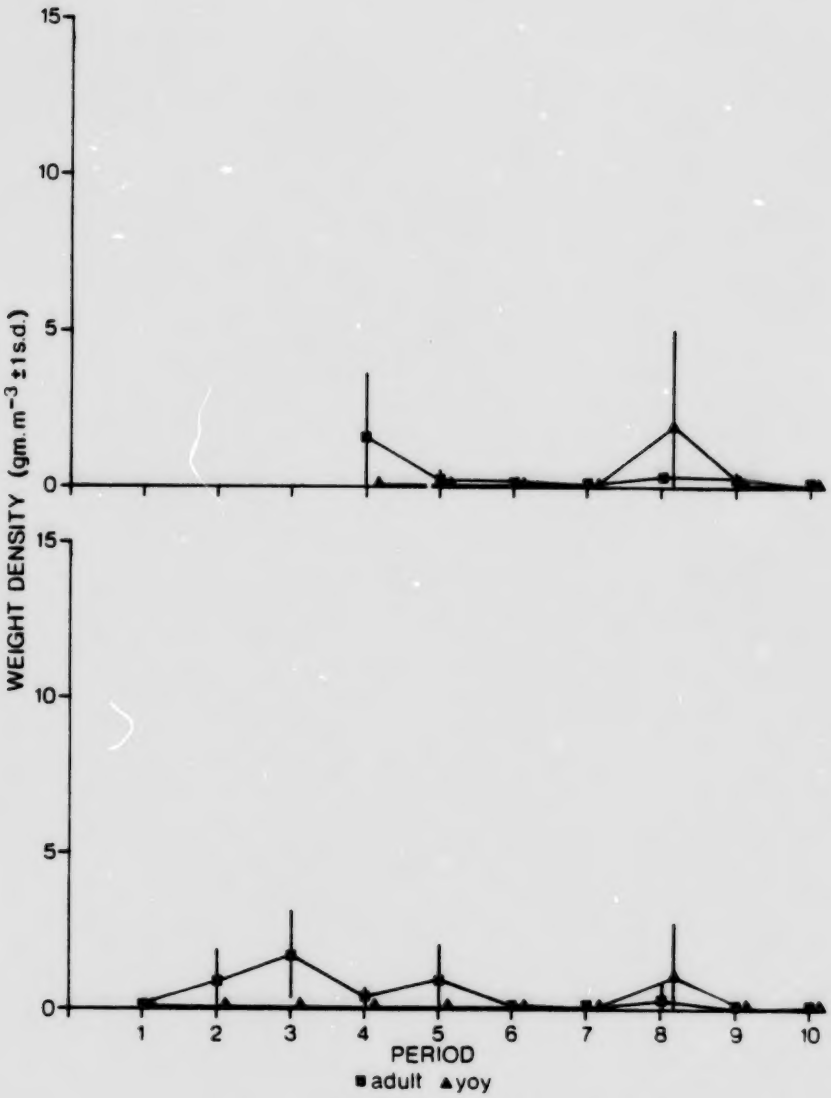

Fig. 18. Temporal changes in weight densities of emerald shiners sampled from the midstream zone of area 1 of the Red River.

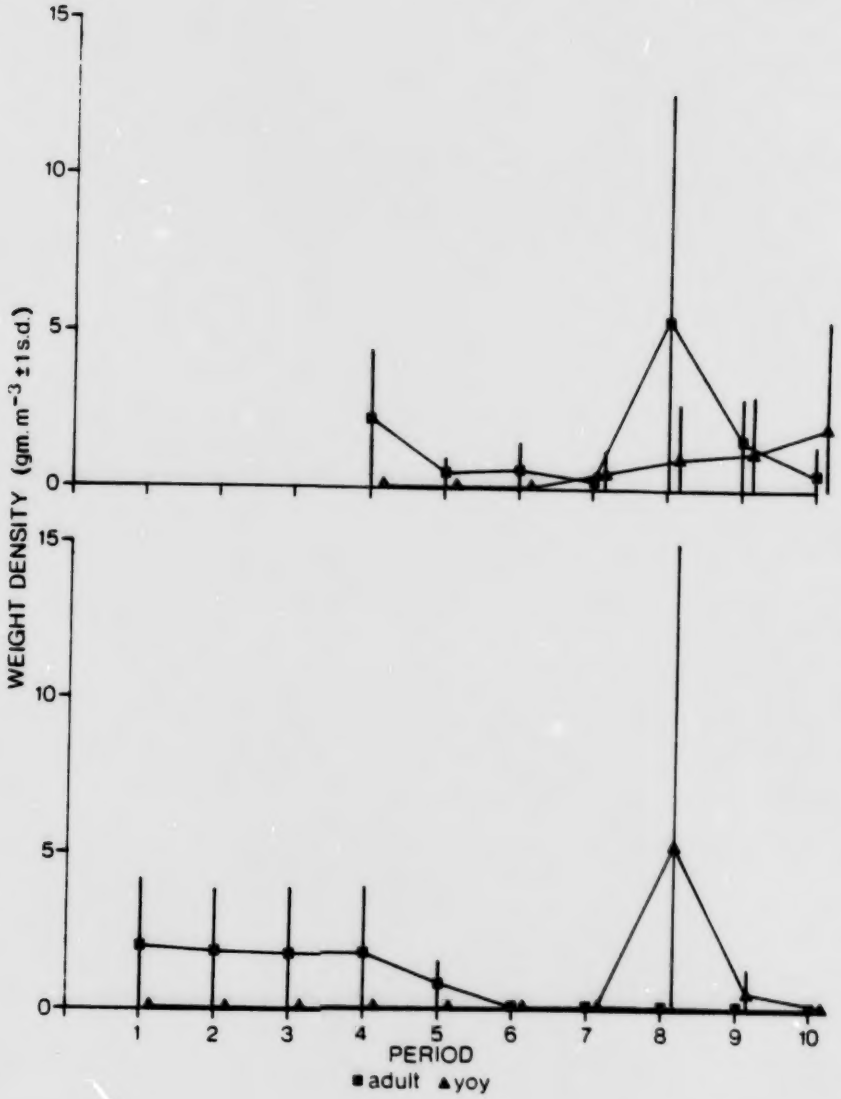

Fig. 19. Temporal changes in pooled weight densities of emerald shiners sampled from area 1 of the Red River.

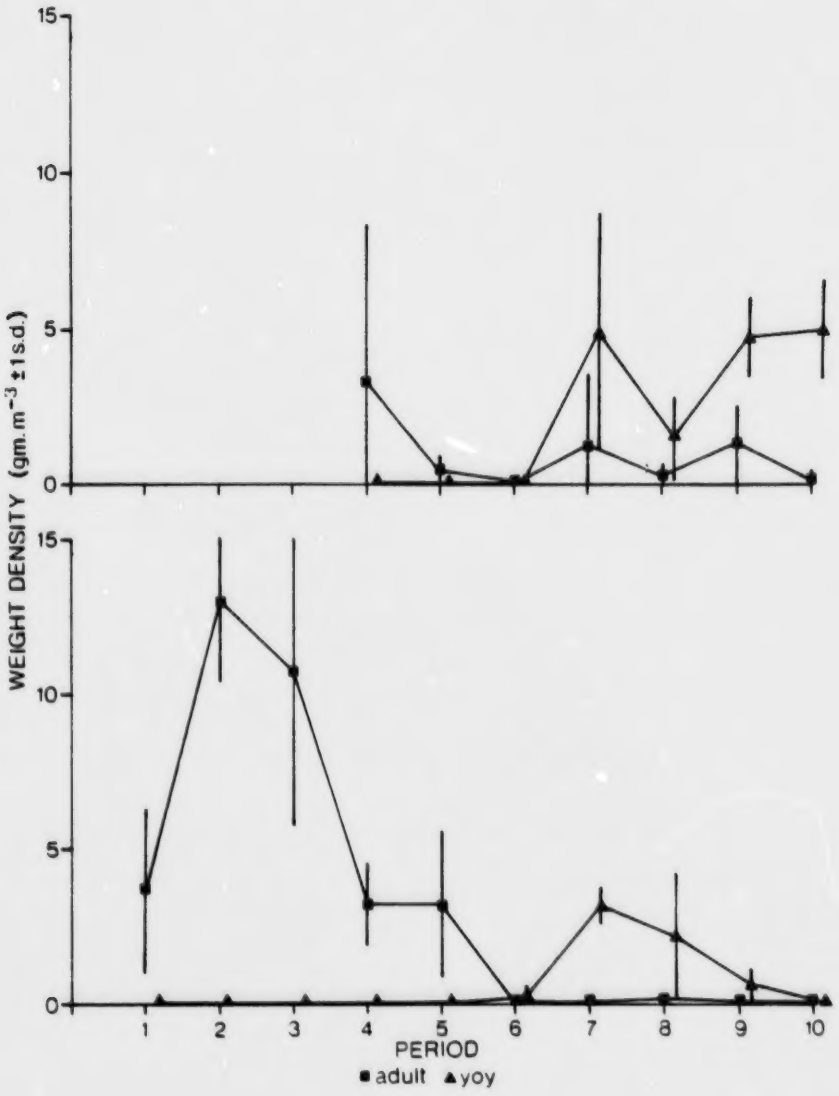

Fig. 20. Temporal changes in weight densities of emerald shiners sampled from the vegetated zone of area 2 of the Red River.

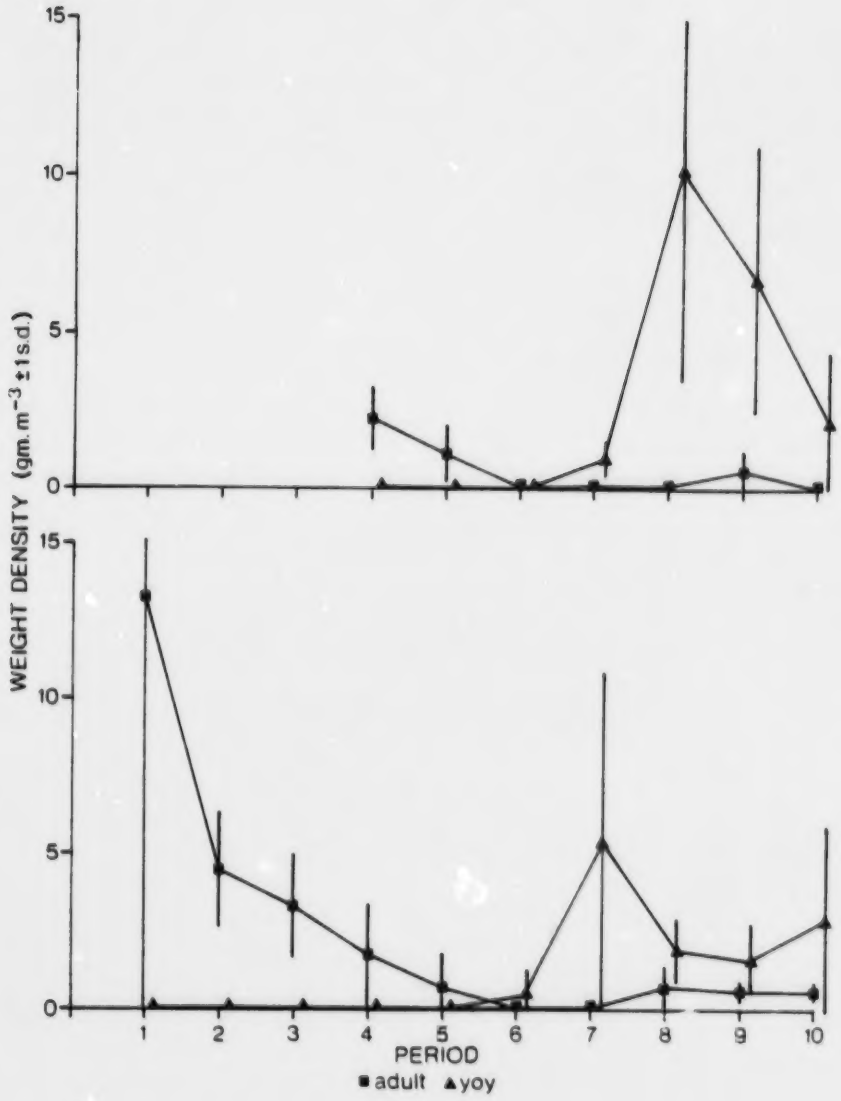

Fig. 21. Temporal changes in weight densities of emerald shiners sampled from the unvegetated zone of area 2 of the Red River.

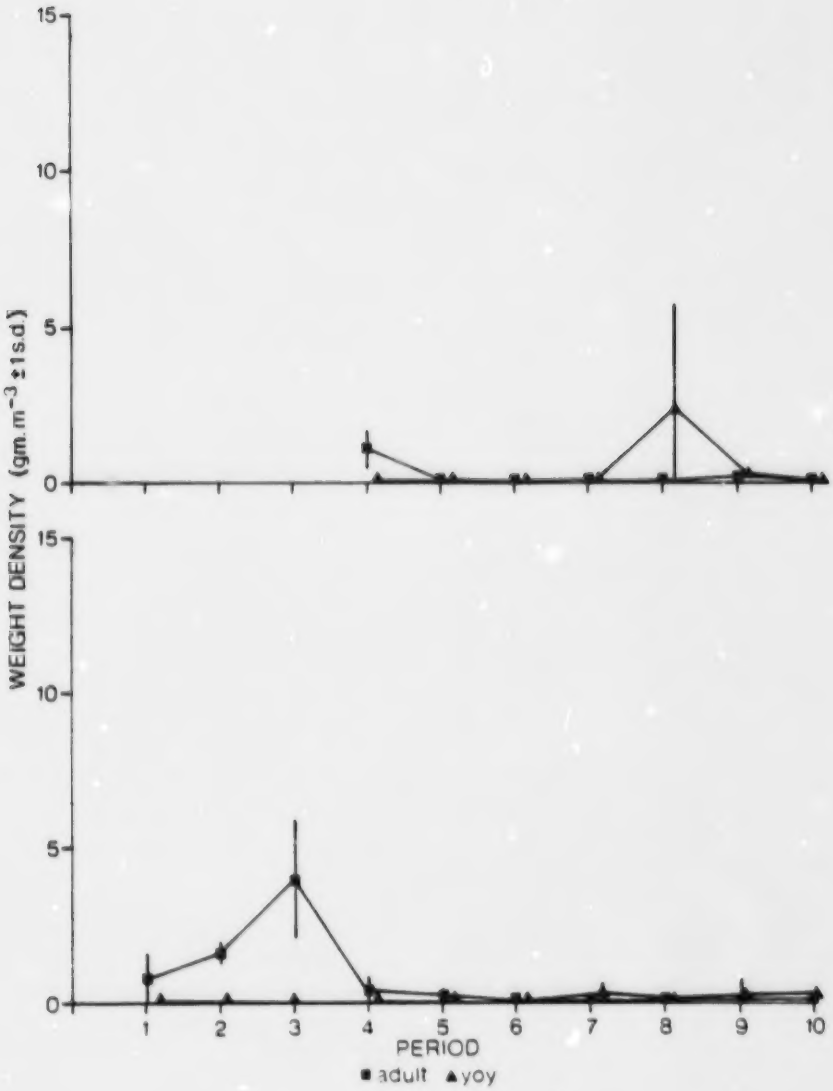

Fig. 22. Temporal changes in weight densities of emerald shiners sampled from the midstream zone of area 2 of the Red River.

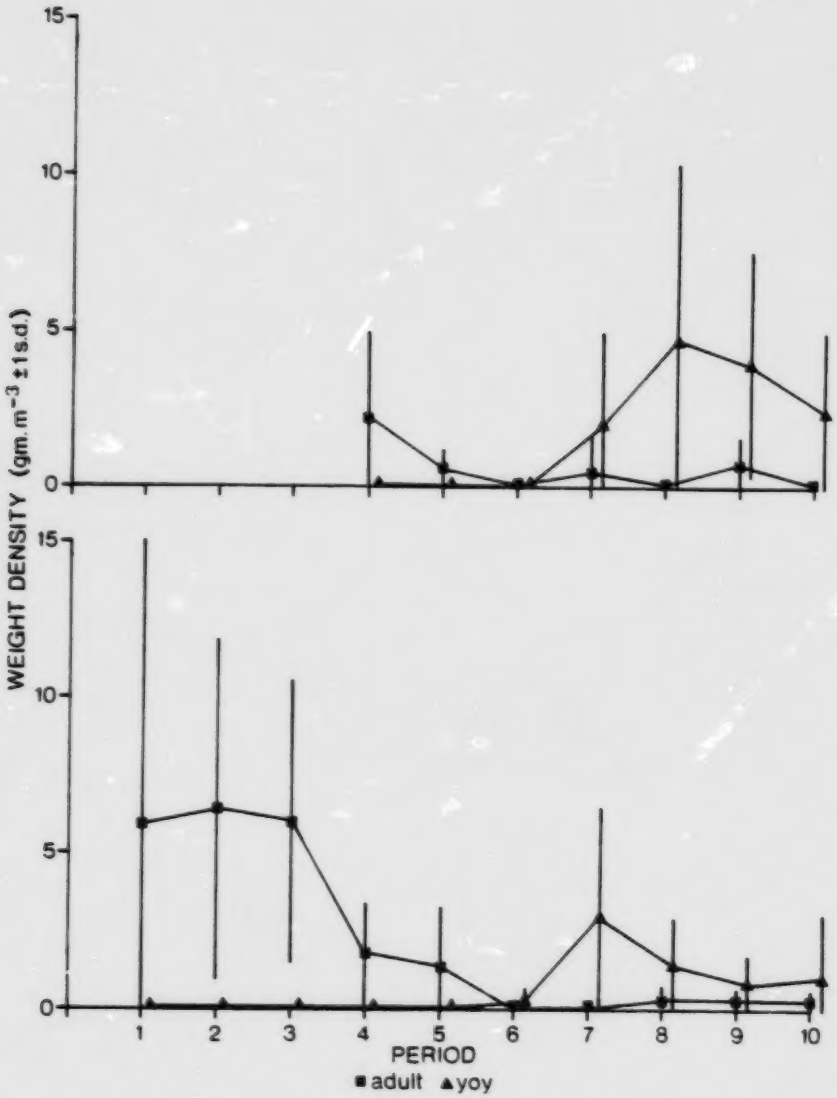

Fig. 23. Temporal changes in pooled weight densities of emerald shiners sampled from area 2 of the Red River.

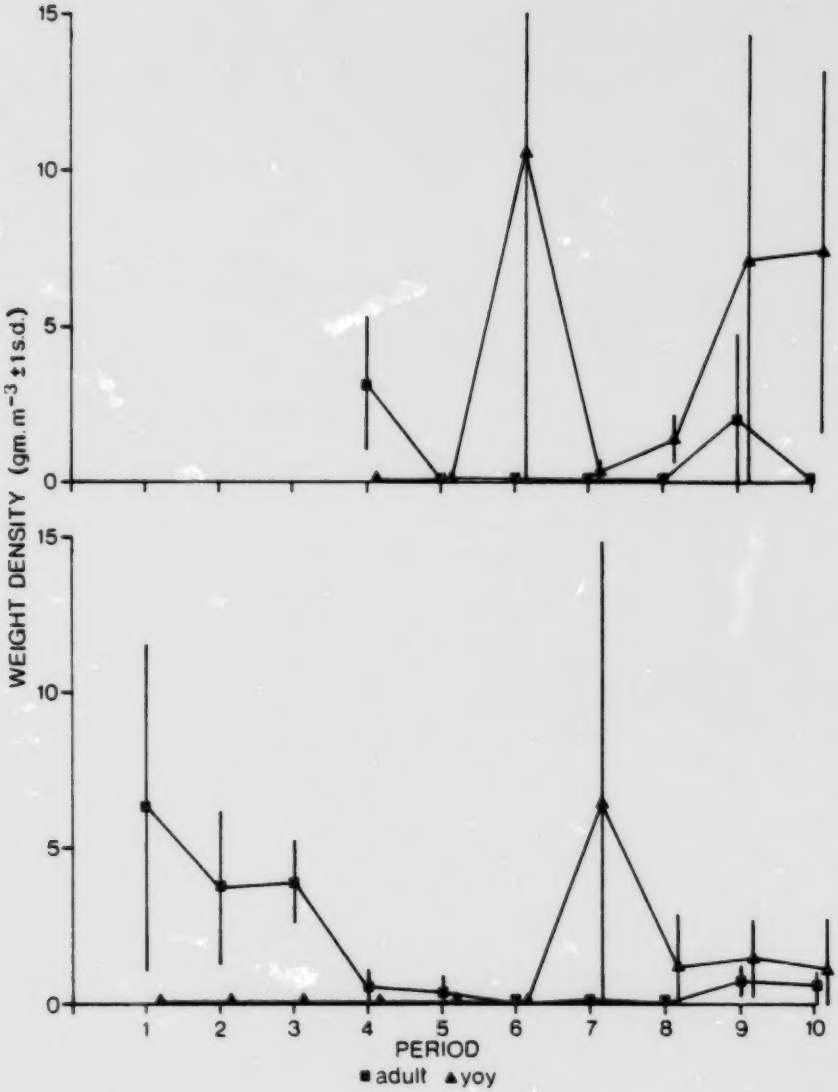

Fig. 24. Temporal changes in weight densities of emerald shiners sampled from the vegetated zone of area 3 of the Red River.

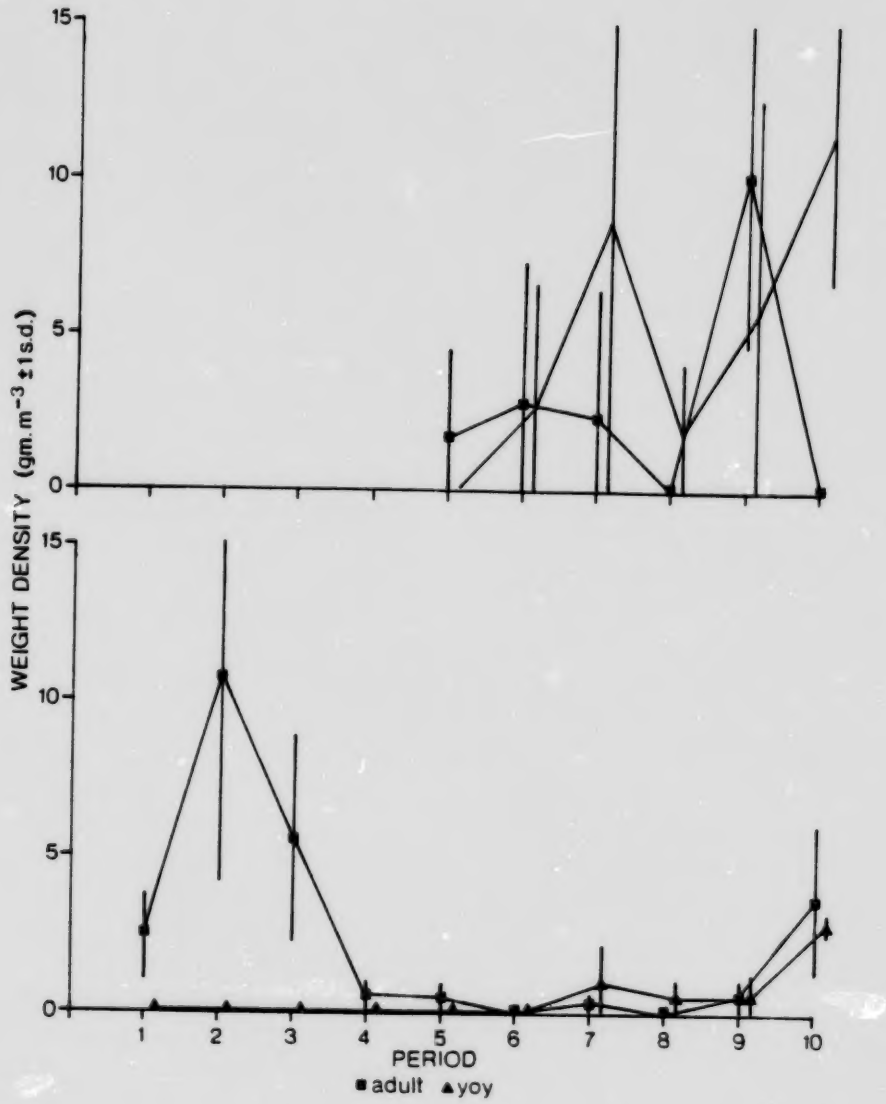

Fig. 25. Temporal changes in weight densities of emerald shiners sampled from the unvegetated zone of area 3 of the Red River.

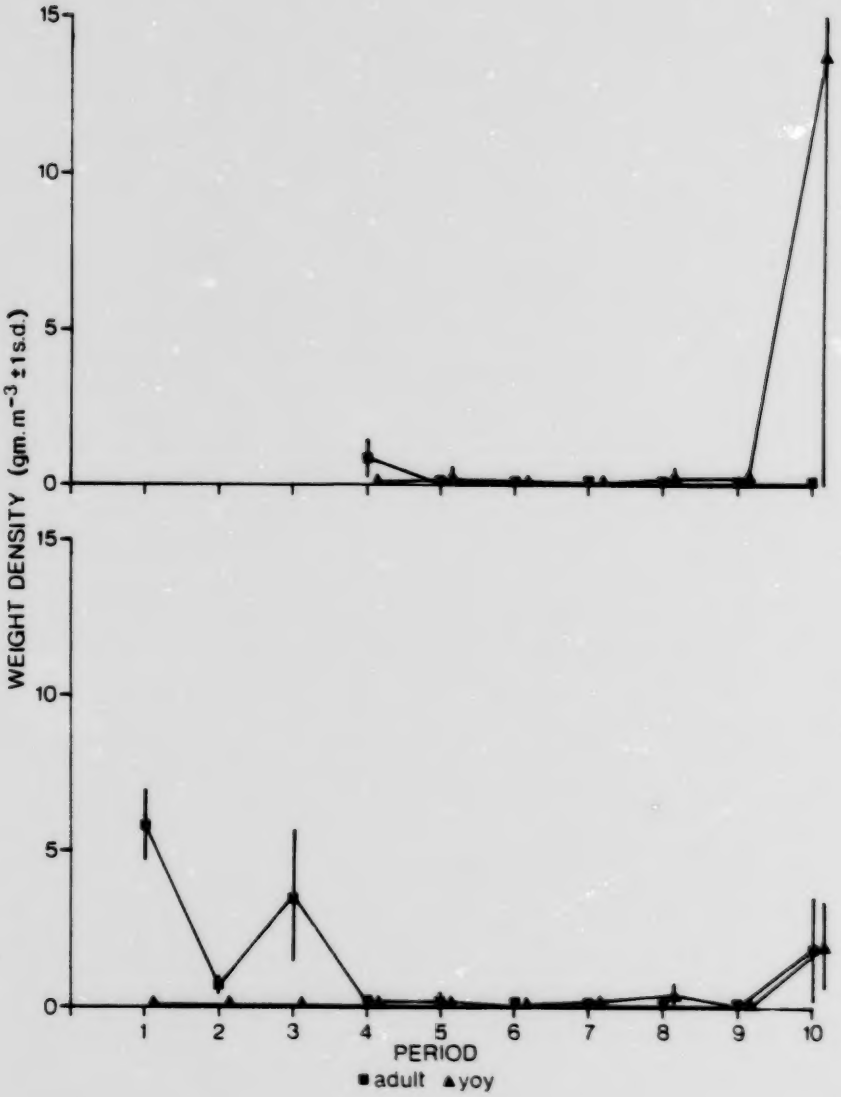

Fig. 26. Temporal changes in weight densities of emerald shiners sampled from the midstream zone of area 3 of the Red River.

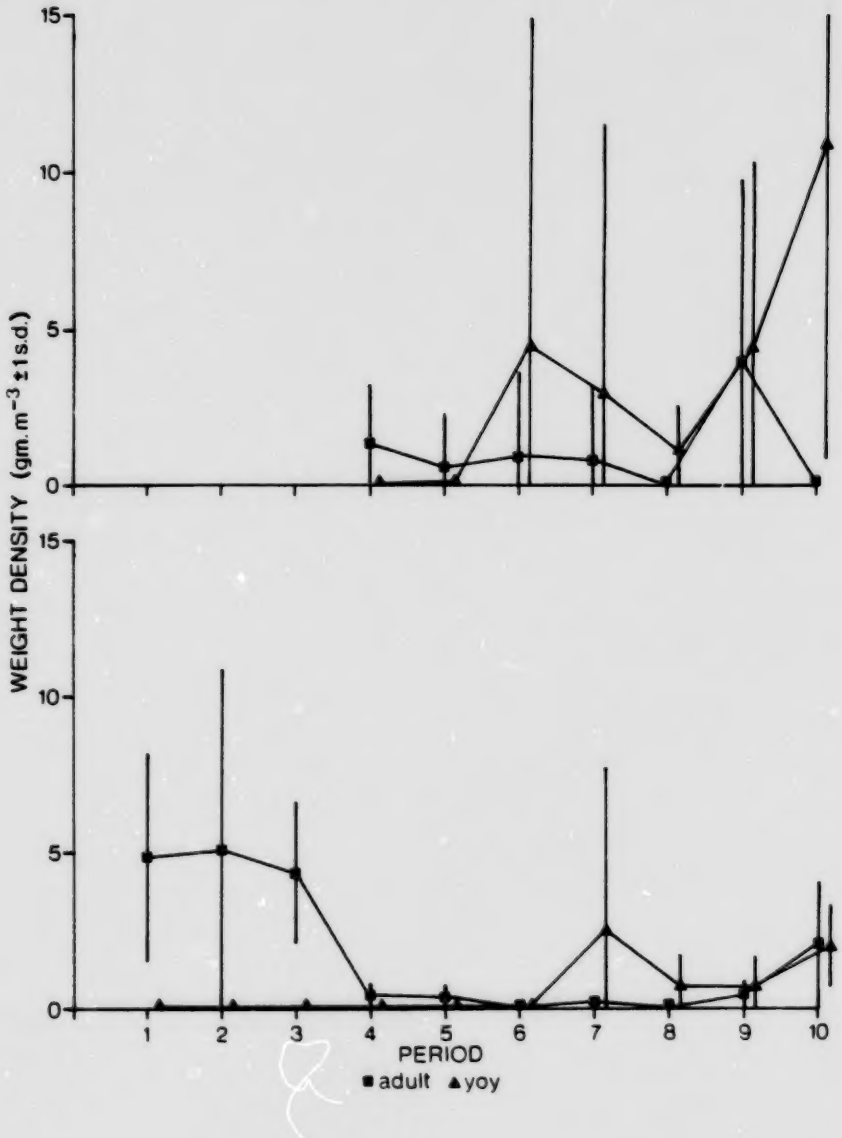

Fig. 27. Temporal changes in pooled weight densities of emerald shiners sampled from area 3 of the Red River.

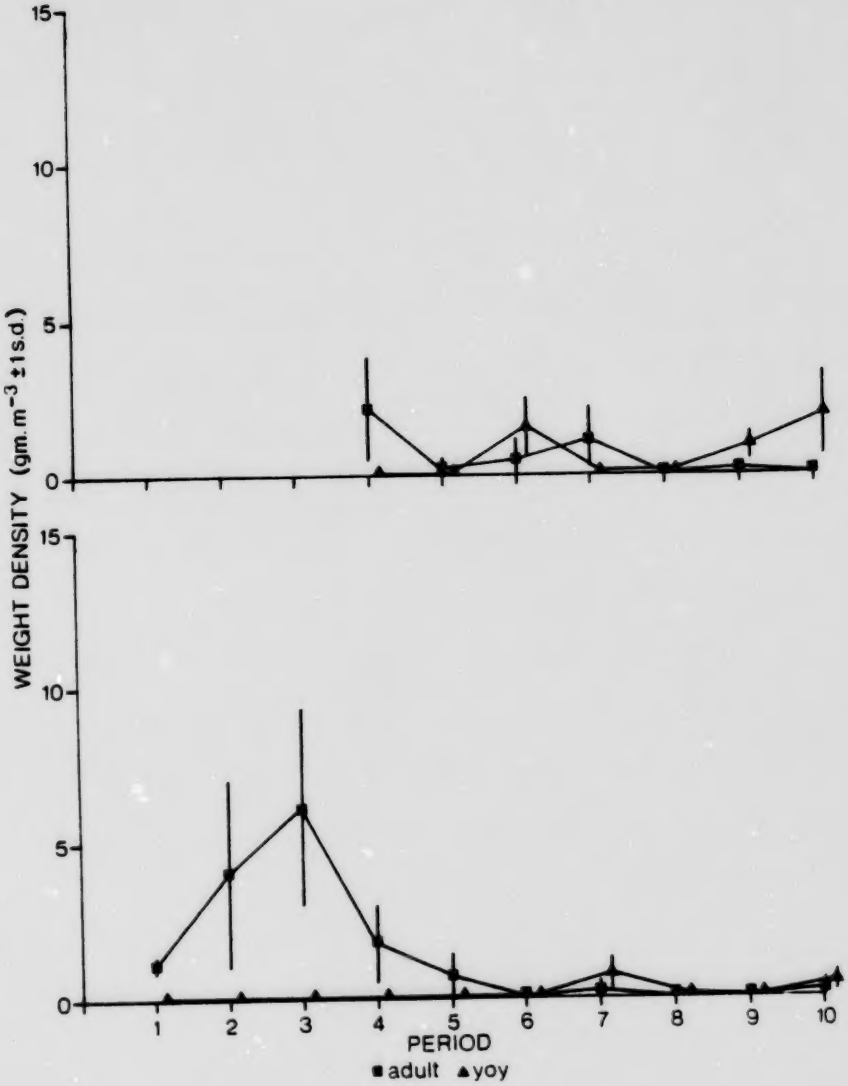

Fig. 28. Temporal changes in weight densities of emerald shiners sampled in Lake Winnipeg.

Effect	Numerical density			Weight density		
	adults	yoy	total	adults	yoy	total
Habitat	*			*		*
Area		*	*		*	*
Period	*			*	*	*

Results of the above ANOVA are tabulated in Appendix E. Interactive effects of habitat type, sampling areas and sampling periods in 1983 could not be determined since samples from the unvegetated habitat of area 3 in period 4 were not collected (Appendix A). These three missing data were estimated using the least squares residuals method. This flaw did not allow the use of a more sophisticated ANOVA model which would account for interactive effects.

A complete data set collected in 1984 permitted examination of interactive effects in all cases. A 1 way ANOVA indicated that sampled water volumes varied significantly (P=0.05) among habitat types, sampling periods and replicates (Appendix F). A 2 way ANOVA indicated the following significant (P=0.05) effects in 1984:

Effect	Numerical density			Weight density		
	adults	yoy	total	adults	yoy	total
Habitat			*	*		*
Area				*		
Period	*	*		*	*	*
Habitat x Area						
Habitat X Area X Period						

Results of the above ANOVAs are tabulated in Appendix F.

Data collected from area 4 (L. Winnipeg at the mouth of the Red River) during 1983 and 1984 were treated separately from data collected from areas 1 - 3 (Red River) because area 4 lacked the habitat types of areas 1 - 3. Thus the only sources of variability were sampling replication and sampling period. Sampling period was a significant source of variation in the majority of cases. Replication did not contribute significantly to variation during 1983 or 1984 (Appendices G and H).

The validity of using no. fish/m^3 and weight of fish/m^3 as abundance indices in the above ANOVAs was questioned because: a) in some cases, habitat type had a significant effect on numerical density but not on weight density, b) the effects of "empty" samples (due to sampling inefficiency or a real absence of adults or juveniles during some sampling periods) on abundance indices were unaccounted and c) it was assumed that densities of fish were constant over the entire range of sampled volumes.

Since both abundance indices used in this study are ratios, it is important to determine whether or not sampled numbers and weights of fish varied significantly over the range of sampled volumes and whether or not these regressions differed among habitat types. For example, if numbers of sampled fish varied in a hyperbolic fashion with sampled volumes and if the coefficients of this function varied significantly among habitat types, it would be erroneous to use no. fish m^{-3} as an abundance index without the appropriate transformation and it would be erroneous to use the transformed index to compare abundances among habitat types. It may also be hypothesized that the numerical density

index as a function of sampled volume varies less among habitats than the weight density index or vice versa. The last confounding factor in these considerations is that some standard tows failed to catch either adult or juvenile emerald shiners. These "empty" samples will affect regressions of numbers or weights of fish on sampled volumes.

To determine whether or not numbers and weights of adult and juvenile fish varied significantly over the range of sampled volumes in each habitat type, least squares linear regressions were performed (Appendix I). In most cases, numbers and weights of adults and juveniles did not vary significantly with sampled volumes. In cases where this relationship was significant, a linear model sufficiently described the relationship. This implies that the range of sampled volumes was relatively small so that sampled numbers and weights either remained constant or changed linearly over this range. In some cases, inclusion of "empty" samples gave rise to a significant regression of the abundance index on sampled volumes while exclusion of these "empty" samples made the relationship non-significant (compare juvenile weights (wt. yoy) from unvegetated habitats including empty samples to those where empty samples were excluded in Appendix I).

The above observations also occurred in an examination of regression of numerical densities (no. fish m^{-3}) and weight densities (gm m^{-3}) on sampled volumes (Appendix J). The effects of autoregression (autocorrelation) in Appendix J were not entirely spurious in light of the regressions listed in Appendix I.

The usual method for comparing the above abundance - volume regressions from different habitats involves performing an ANCOVA on each pair of curves. Twenty eight ANCOVAs are required to compare 11 possible combinations of abundance - volume regressions for each type of abundance index from the four habitats in the case where empty samples were included in deriving the regressions. Fifty six more ANCOVA's are required for comparisons in the case where empty samples were excluded from deriving the abundance - volume regressions.

To avoid interpreting the results of 112 ANCOVA'a, a graphical method using confidence interval ellipses was employed. 95% confidence intervals about the intercepts and slopes of regressions listed in Appendices I and J were calculated (Tables 1 and 2). These confidence intervals were used to construct confidence ellipses about plots of intercepts, $\hat{\beta}_0$ and slopes, $\hat{\beta}_1$ (Figs. 29 - 32 correspond to cases listed in Table 1. Figs. 33 - 36 correspond to cases listed in Table 2).

The following characteristics are common among all 8 plots (Figs. 29 - 36):

a. the abundance - volume regressions for adult emerald shiners have positive slopes and negative intercepts.

b. the abundance - volume regressions for juvenile (yoy) emerald shiners have negative slopes and positive intercepts.

c. The abundance - volume regression from adult fish from the vegetated habitat has the highest (+) slope and the lowest (-) intercept, except in Fig. 34.

Table 1. Relationships of sampled volumes to total numbers and total weights of emerald shiners caught per tow in the Red River, 1984. Numbers and letters in parentheses correspond to ellipses in Figs. 29-32.

Habitat	Abundance index	d.f.	$\hat{\beta}_0$	S.E.	95% C.I.	$\hat{\beta}_1$	S.E.	95% C.I.	
INCLUDING EMPTY SAMPLES									
Lake (Area 4)	no. adults	28	- 29.497	179.98	± 368.60	1.3496	2.54063	± 5.203	(1)
	wt. adults	28	114.88	355.47	± 728.00	- 0.2102	5.0179	±10.277	(a)
	no. yoy	28	- 46.296	137.62	± 281.85	1.0809	1.9427	± 3.979	(2)
	wt. yoy	28	- 8.9686	48.599	± 99.53	0.2828	0.6860	± 1.405	(b)
Unvegetated (Areas 1-3)	no. adults	88	- 398.06	642.69	±1276.38	7.6749	9.1097	±18.092	(3)
	wt. adults	88	- 338.03	402.02	± 798.41	6.7172	5.6984	±11.32	(c)
	no. yoy	88	1155.0	482.79	± 958.82	-14.529	6.8432	±13.59	(4)
	wt.yoy	88	435.42	126.78	± 251.79	- 5.5948	1.7970	± 3.57	(d)
Vegetated (Areas 1-3)	no. adults	88	-1411.2	535.86	±1064.22	22.191	7.4804	±14.86	(5)
	wt. adults	88	-1058.8	342.54	± 680.28	17.109	4.7817	± 9.50	(e)
	no. yoy	88	767.42	1049.7	±2084.70	- 7.9993	14.654	±29.10	(6)
	wt. yoy	88	323.18	460.87	± 915.29	- 3.4543	6.4336	±12.78	(f)
Midstream (Areas 1-3)	no. adults	88	-1001.8	331.54	± 658.44	14.857	4.6089	± 9.15	(7)
	wt. adults	88	- 554.85	180.59	± 358.65	8.5858	2.5104	± 4.99	(g)
	no. yoy	88	211.31	109.98	± 218.42	- 2.6314	1.5288	± 3.07	(8)
	wt. yoy	88	101.06	62.561	± 124.25	- 1.2483	0.8697	± 1.73	(h)

Habitat	Abundance index	d.f.	$\hat{\beta}_0$	S.E.	95% C.I.	$\hat{\beta}_1$	S.E.	95% C.I.	
EXCLUDING EMPTY SAMPLES									
Lake	no. adults	23	-4.6395	195.61	± 404.72	1.1812	2.7545	± 5.70	(1)
(Area 4)	wt. adults	23	170.71	397.44	± 822.30	- 0.7160	5.5964	±11.58	(a)
	no. yoy	13	- 212.28	283.35	± 612.04	3.8786	4.0257	± 8.70	(2)
	wt. yoy	13	- 55.829	99.681	± 215.31	1.1085	1.4162	± 3.06	(b)
Unvegetated	no. adults	69	- 290.53	831.02	±1657.05	6.6271	11.680	±23.29	(3)
(Areas 1-3)	wt. adults	69	- 223.21	513.17	±1023.26	5.5473	7.2125	±14.38	(6)
	no. yoy	46	702.39	927.67	±1868.33	- 6.7021	13.707	±27.61	(4)
	wt. yoy	46	376.18	241.37	± 486.12	4.4077	3.5666	± 7.18	(d)
Vegetated	no. adults	69	-1321.5	649.45	±1295.00	21.384	8.9793	±17.90	(5)
(Areas 1-3)	wt. adults	69	- 926.47	405.76	± 809.09	15.718	5.6101	±11.19	(e)
	no. yoy	46	-1074.5	2075.1	±4179.25	20.954	30.073	±60.57	(6)
	wt. yoy	46	- 364.71	918.73	±1850.32	7.3819	13.315	±26.82	(f)
Midstream	no. adults	67	-1234.9	439.08	± 875.53	18.249	6.0617	±12.09	(7)
(Areas 1-3)	wt. adults	67	- 622.17	233.06	± 464.72	9.7157	3.2176	± 6.42	(g)
	no yoy	41	3.9705	245.46	± 496.07	0.6197	3.5412	± 7.16	(8)
	wt. yoy	41	- 16.432	140.70	± 284.35	0.5834	2.0299	± 4.10	(h)

Table 2. Relationships of sampled volumes to numerical densities and weight densities of emerald shiners in the Red River, 1984. Numbers and letters in parentheses correspond to ellipses in Figs. 33-36.

Habitat	Abundance index	d.f.	$\hat{\beta}_0$	S.E.	95% C.I.	$\hat{\beta}_1$	S.E.	95% C.I.	
INCLUDING EMPTY SAMPLES									
Lake (Area 4)	no. adults	28	0.7121	2.5733	± 5.270	0.0031	0.0363	± 0.0743	(1)
	wt. adults	28	2.7545	5.0897	±10.424	- 0.0188	0.0718	± 0.1471	(a)
	no. yoy	28	- 0.2423	1.8632	± 3.8158	0.0094	0.0263	± 0.0539	(2)
	wt. yoy	28	0.0187	0.6675	± 1.3670	0.0019	0.0094	± 0.0193	(b)
Unvegetated (Areas 1-3)	no. adults	88	- 4.7040	9.0195	±17.907	0.0949	0.1279	± 0.2538	(3)
	wt. adults	88	- 3.6624	5.6556	±11.226	0.0787	0.0802	± 0.1591	(c)
	no. yoy	88	18.831	7.2820	±14.460	- 0.2392	0.1032	± 0.2049	(4)
	wt. yoy	88	7.0102	1.9195	± 3.813	- 0.0906	0.0272	± 0.0540	(d)
Vegetated (Areas 1-3)	no. adults	88	-17.277	7.0546	±13.815	0.2743	0.0985	± 0.1956	(5)
	wt. adults	88	-12.619	4.6527	± 9.111	0.2074	0.0650	± 0.1289	(e)
	no. yoy	88	11.898	14.646	±28.687	- 0.1274	0.2045	± 0.4061	(6)
	wt. yoy	88	5.0243	6.4029	±12.538	- 0.0550	0.0894	± 0.1775	(f)
Midstream (Areas 1-3)	no. adults	88	-12.203	4.2067	± 8.238	0.1818	0.0585	± 0.1161	(7)
	wt. adults	88	- 6.7164	2.3956	± 4.691	0.1051	0.0333	± 0.0661	(g)
	no. yoy	88	3.2552	1.5888	± 3.156	- 0.0408	0.0221	± 0.0438	(8)
	wt. yoy	88	1.5488	0.8946	± 1.777	- 0.0193	0.0124	± 0.0247	(h)

Habitat	Abundance index	d.f.	$\hat{\beta}_o$	S.E.	95% C.I.	$\hat{\beta}_1$	S.E.	95% C.I.	
EXCLUDING EMPTY SAMPLES									
Lake	no. adults	23	1.1910	2.7969	± 5.761	- 0.0011	0.0394	± 0.0811	(1)
(Area 4)	wt. adults	23	3.6765	5.6870	±11.766	- 0.0278	0.0801	± 0.1656	(a)
	no. yoy	13	- 1.8580	3.8379	± 8.290	0.0384	0.0545	± 0.1179	(2)
	wt. yoy	13	- 0.3879	1.3708	± 2.962	0.0099	0.0195	± 0.0420	(b)
Unvegetated	no. adults	69	- 2.9378	11.663	±23.254	0.0766	10.1639	± 0.3268	(3)
(Areas 1-3)	wt. adults	69	- 1.7188	7.2184	±14.401	0.0577	0.1015	± 0.2023	(c)
	no. yoy	46	13.684	14.028	±27.005	- 0.1470	0.2073	± 0.4175	(4)
	wt. yoy	46	6.5486	3.6573	± 7.040	0.0793	0.0540	± 0.1088	(d)
Vegetated	no. adults	69	-15.802	8.5434	±17.032	0.2599	0.1181	± 0.2354	(5)
(Areas 1-3)	wt. adults	69	-10.542	5.5080	±10.982	0.1848	0.0762	± 0.1518	(e)
	no. yoy	46	-13.198	28.950	±58.314	0.2680	0.4196	± 0.8450	(6)
	wt. yoy	46	- 4.3059	12.760	±25.696	0.0924	0.1849	± 0.3723	(f)
Midstream	no. adults	67	-14.893	5.5727	±11.111	0.2214	0.0769	± 0.1533	(7)
(Areas 1-3)	wt. adults	67	- 7.3324	3.0922	± 6.166	0.1164	0.0427	± 0.0851	(g)
	no. yoy	41	0.5996	3.5575	± 7.189	0.0011	0.0513	± 0.1037	(8)
	wt. yoy	41	0.0118	2.0159	± 4.073	0.0048	0.0291	± 0.0587	(h)

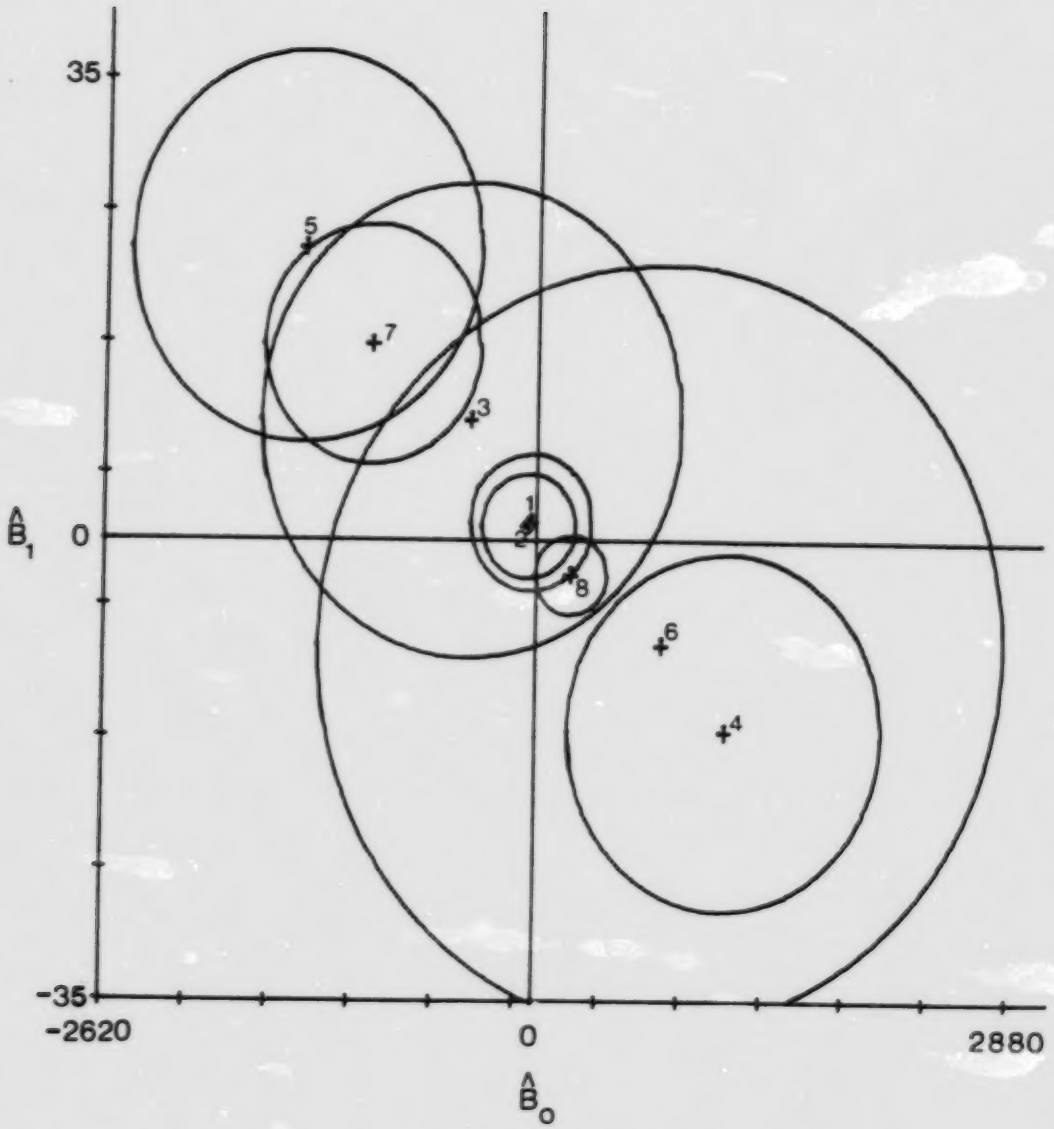

Fig. 29. Confidence ellipses demonstrating effects of habitat types on the relations of numbers of captured adult and juvenile fish and sampled volumes. Empty samples were included.

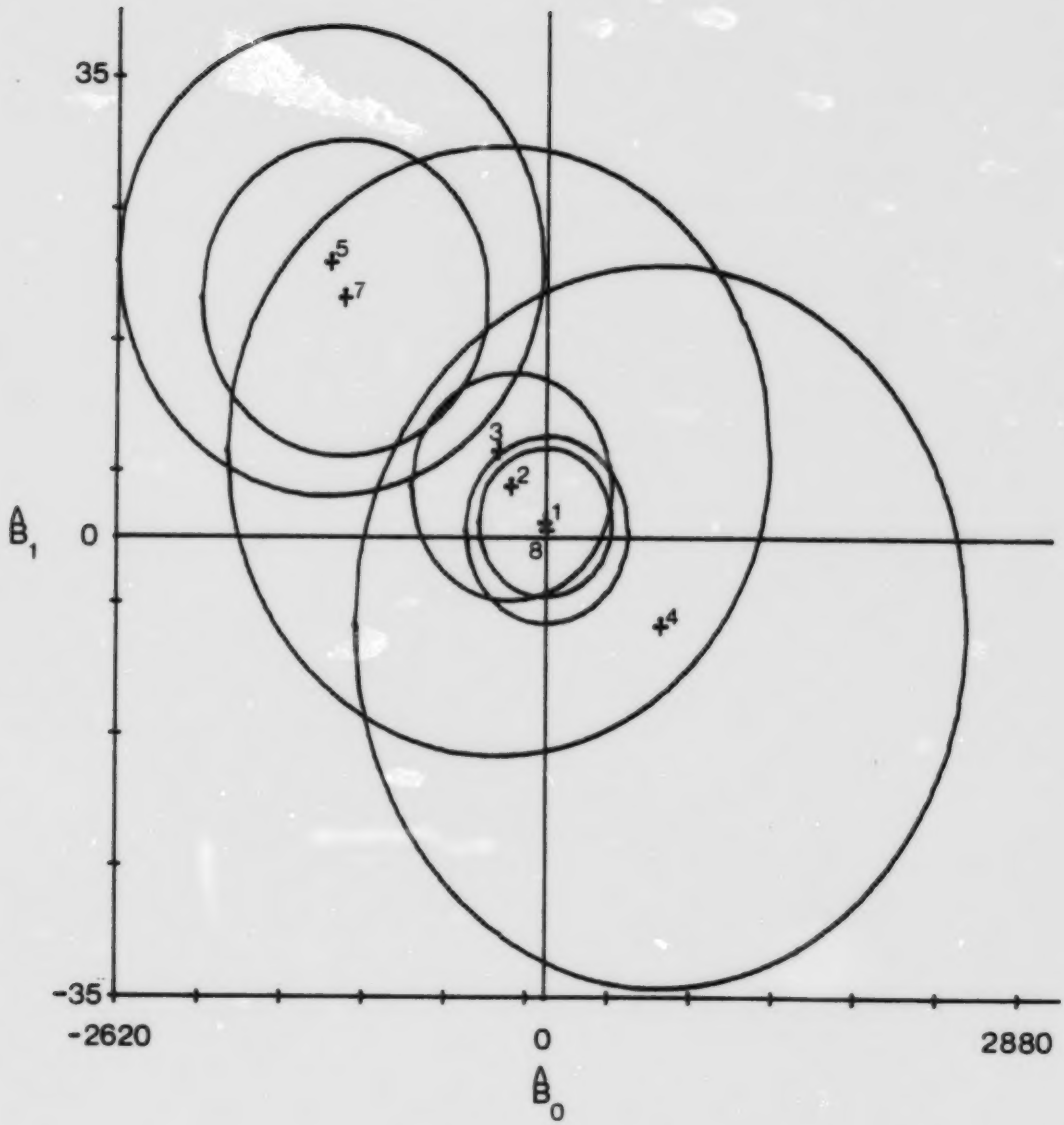

Fig. 30. Confidence ellipses demonstrating effects of habitat types on the relations of numbers of captured adult and juvenile fish and sampled volumes. Empty samples were excluded. Ellipse 6 is inordinately large.

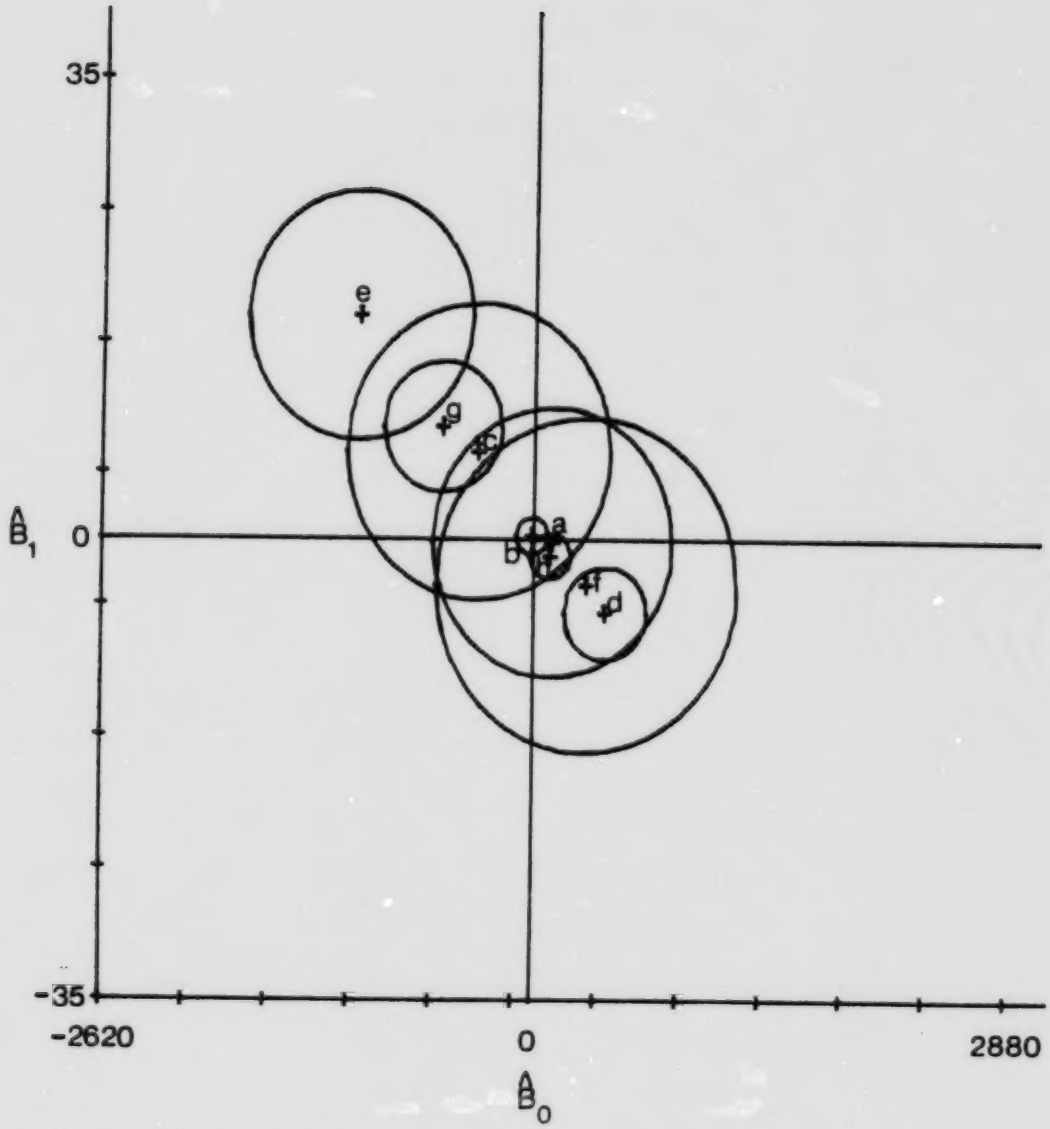

Fig. 31. Confidence ellipses demonstrating effects of habitat types on the relations of weights of captured adult and juvenile fish and sampled volumes. Empty samples were included.

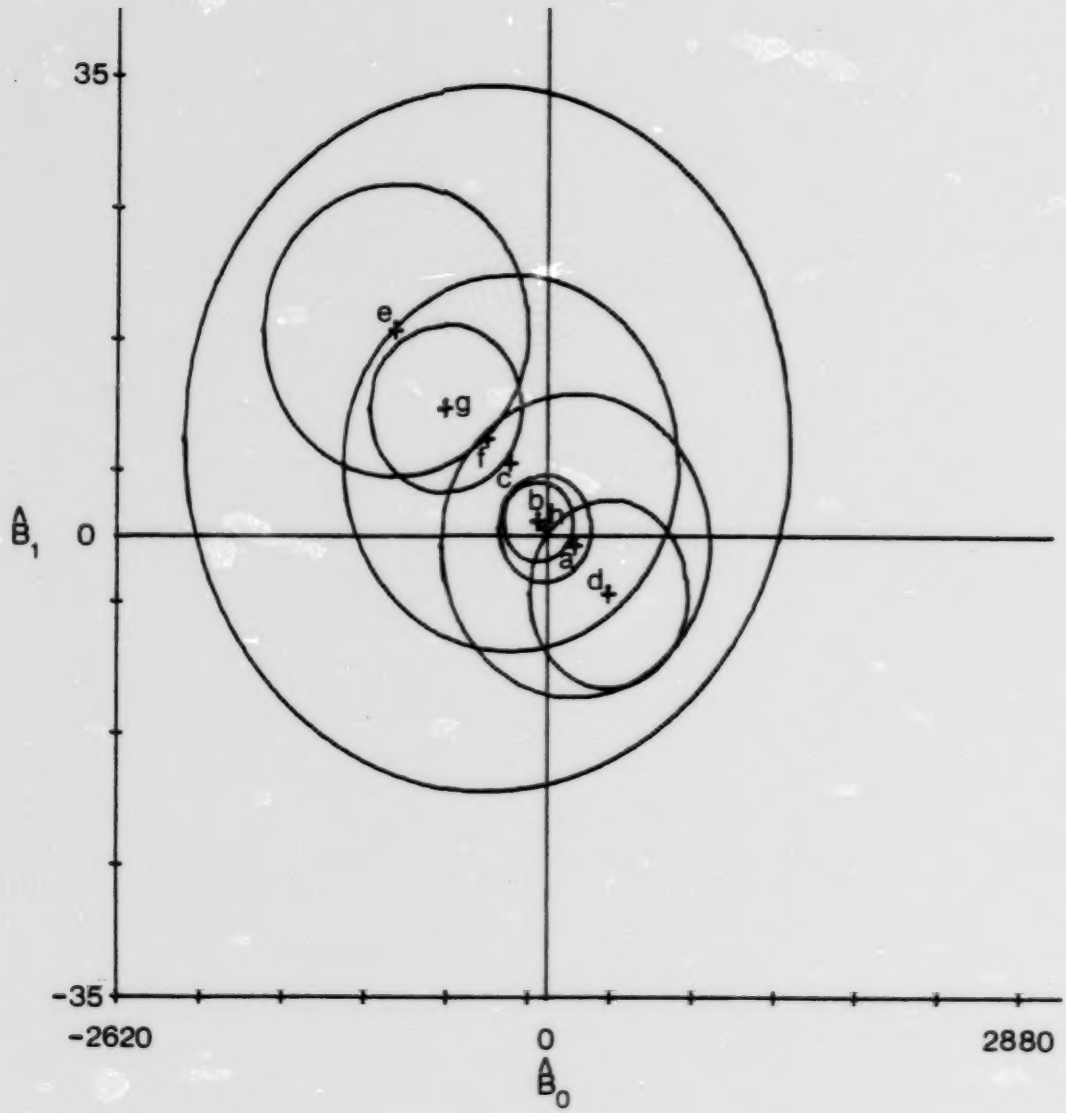

Fig. 32. Confidence ellipses demonstrating effects of habitat types on the relations of weights of captured adult and juvenile fish and sampled volumes. Empty samples were excluded.

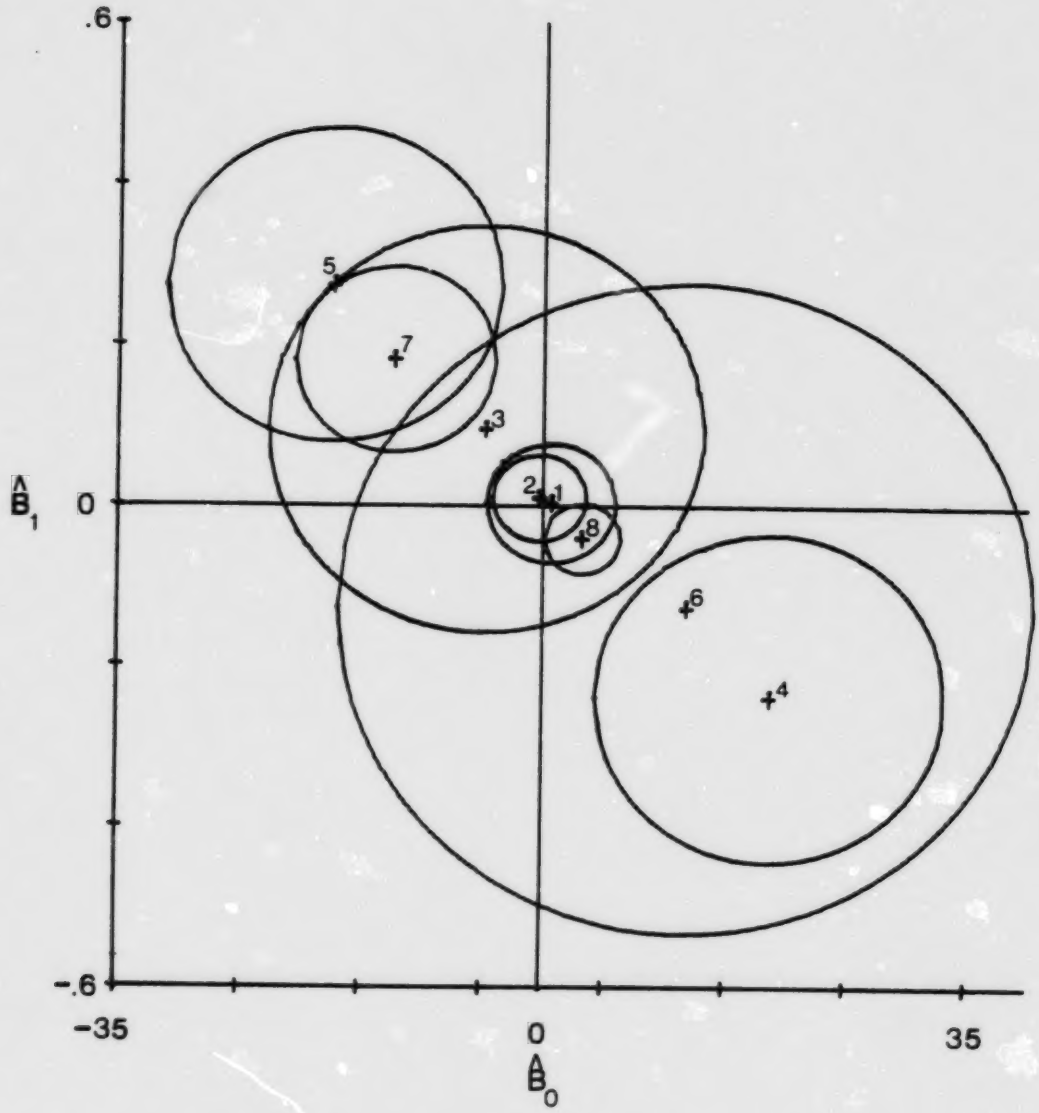

Fig. 33. Confidence ellipses demonstrating effects of habitat types on the relations of numerical densities of captured adult and juvenile fish and sampled volumes. Empty samples were included.

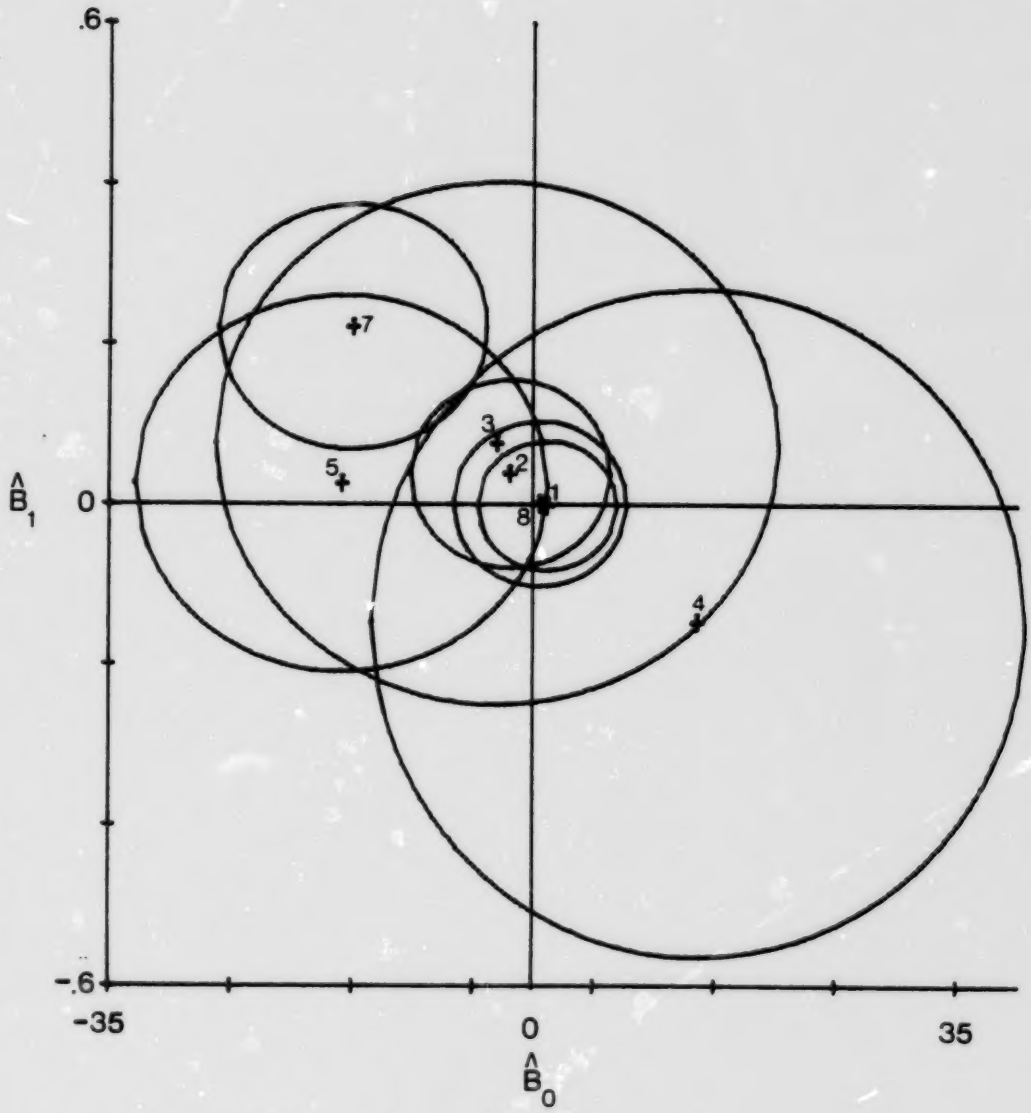

Fig. 34. Confidence ellipses demonstrating effects of habitat types on the relations of numerical densities of captured adult and juvenile fish and sampled volumes. Empty samples were excluded. Ellipse 6 is inordinately large.

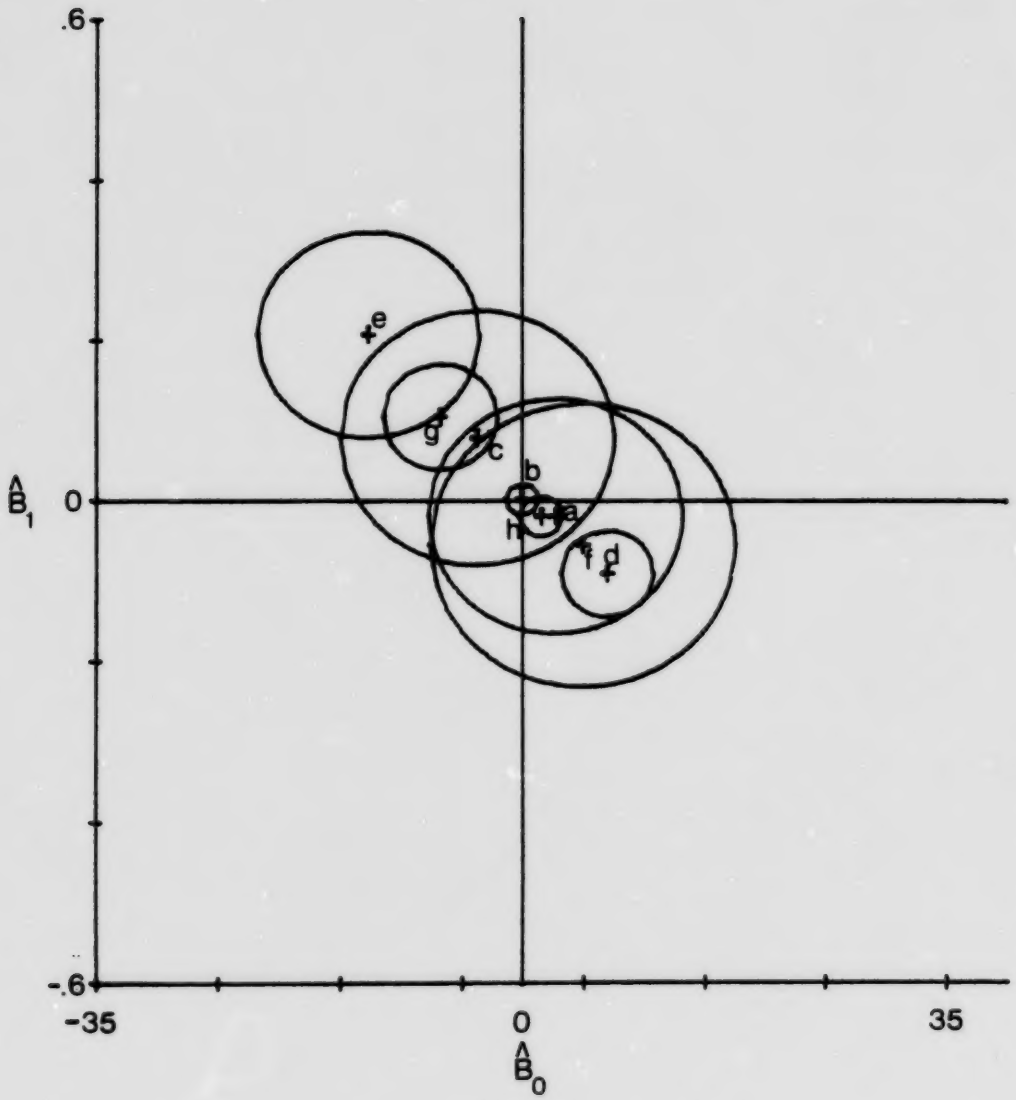

Fig. 35. Confidence ellipses demonstrating effects of habitat types on the relations of weight densities of captured adult and juvenile fish and sampled volumes. Empty samples were included.

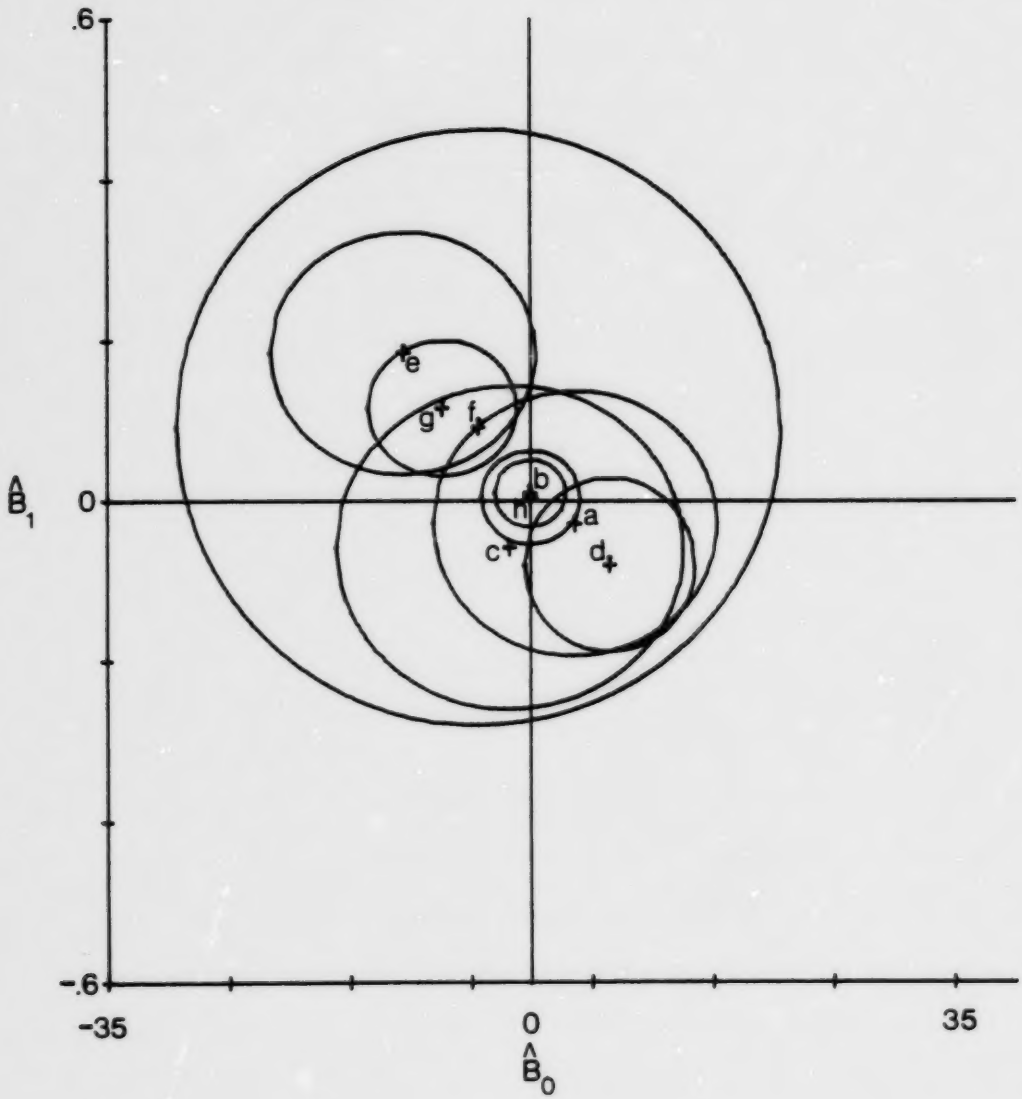

Fig. 36. Confidence ellipses demonstrating effects of habitat types on the relations of weight densities of captured adult and juvenile fish and sampled volumes. Empty samples were excluded.

d. The abundance - volume regression for juvenile fish from the unvegetated habitat has the lowest (-) slope and the highest (+) intercept.

e. The confidence ellipse for juvenile fish from the vegetated habitat is the largest ellipse. This implies that the method for sampling juvenile shiners in vegetated habitats was poor and that the associated abundance indices are markedly imprecise.

f. The slopes and intercepts of abundance - volume regressions for adults and juveniles from the lake habitat and for juveniles from the midstream habitat were relatively close to 0. This implies extremely low abundance or highly contagious distribution or both in these cases.

Two types of comparisons remain. The first compares ellipse patterns when empty samples are included in the abundance - volume regressions to patterns when empty samples are excluded. In all cases, exclusion of empty samples increases the size of the ellipses but decreases the coordinate range of points (i.e., slopes and intercepts tend to approach 0). The second compares ellipse patterns of numerical index - volume regressions to patterns of weight index - volume regressions. In all cases, the weight index ellipses are smaller and cluster closer to the origin than the numerical index ellipses.

Patterns of point coordinates do not change between numerical and weight index plots. For example, the intercept - slope coordinate for adult fish from the vegetated habitat remains at the upper left extreme of both numerical and weight coordinate spectra while the intercept - slope coordinate for juvenile fish from the unvegetated habitat retains its position at the lower right extreme. The higher degree of clustering about the origin and the smaller ellipses of the weight index ellipses imply that the weight density index (gm m-3) should be used in quantitative comparisons of fish abundance among habitat types.

Abundance indices of adult fish increases towards the upper left extremity and abundance indices of juvenile fish increase toward the lower right extremity of the slope intercept plots (Fig. 37A). Thus, adult fish were most abundant in vegetated habitats and least abundant in the lake and midstream habitats, Juvenile fish were most abundant in the unvegetated and vegetated habitats and least abundant in the lake and midstream habitats. The opposing patterns in Fig. 37a imply that the towing method in this study sampled adults and juveniles at different efficiencies or that adult and juvenile spatial distributions exhibited different degrees of contagion. Since our sampled volumes were relatively low and since their range was low (about 50 - 90 m^{-3}), many of the abundance - volume regressions were non-significant. This resulted in huge variability of the intercepts, $\hat{\beta}_o$ and large confidence ellipses. Numbers of yoy fish decreased while numbers of adult fish increased with increasing sample volumes (Fig. 37B). Increasing our towing distance from length A to lengths B or C (Fig. 37C) would undoubtedly change the abundance - volume regressions

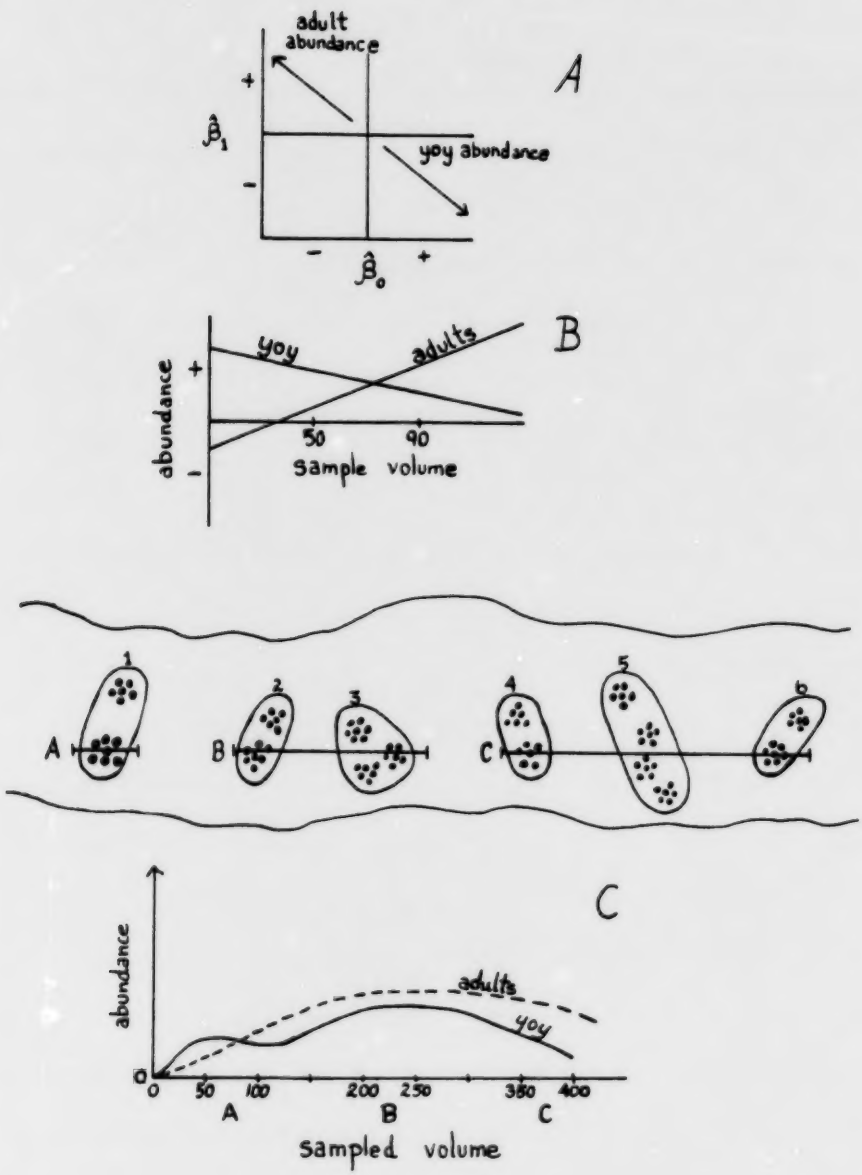

Fig. 37. Effects of varying sampled volumes relative to spatial contagion on abundance indices.

and the size of their confidence ellipses. The relation of sampled abundance to varying towing distances, A, B and C would depend not only on numbers of fish in a "patch" (denoted by 1, 2, 3 ...6) but also on distances between patches and patterns of larger aggregations, i.e. "clumps of patches" (Fig. 37C). A unimodal curve of abundance over sampled volumes would indicate a simple contagious distribution where distances between patches were very short. A plurimodal curve of abundance over sampled volumes would indicate that patches were discrete and separated by appreciable distances. In both cases, sampled abundance would eventualy decrease at very high volumes since the townets would become plugged with large numbers of fish. Also, the risk of towing through various types of habitats would increase.

The above analysis was repeated to determine relative abundance of emerald shiners in various sampling areas (Table 3, Figs. 38 - 41). Slope and intercept values listed on Table 3 are from Appendix K. The abundances of adults and juveniles were highest in sampling area 2 and were lowest in areas 1 and 3. Again, weight density-volume regressions produced smaller confidence ellipses and smaller ranges of slope intercept coordinates than numerical density-volume regressions (compare Fig. 38 to Fig. 40). Exclusion of empty samples gave rise to larger ellipses (compare Fig. 38 to Fig. 39 and Fig. 40 to Fig. 41).

Temporal changes in both numerical and weight densities of adult emerald shiners in most areas and habitats were characterized by vernal and autumnal concentrations. Adult fish dispersed in early July. Adult dispersion was followed by rapidly increasing

Table 3. Relationships of sampled volumes to numerical densities and weight densities of emerald shiners in the Red River, 1984. Numbers and letters in parentheses correspond to ellipses in Figs. 38-41.

Area	Abundance index	d.f.	$\hat{\beta}_o$	S.E.	95% C.I.	$\hat{\beta}_1$	S.E.	95% C.I.	
INCLUDING EMPTY SAMPLES									
Area 1	no. adults	88	- 2.2229	2.2430	± 5.112	- 0.0396	0.0311	± 0.071	(1)
(all habitats)	wt. adults	88	- 2.2031	2.3267	± 5.303	- 0.0425	0.0323	± 0.074	(a)
	no. yoy	88	- 3.2659	13.462	± 30.680	- 0.0274	0.1867	± 0.425	(2)
	wt. yoy	88	1.6632	6.5690	± 14.971	- 0.0144	0.0911	± 0.208	(b)
Area 2	no. adults	88	-11.891	9.8546	±22.459	0.2015	0.1385	± 0.316	(3)
(all habitats)	wt. adults	88	-11.590	6.1086	±13.921	0.1953	0.0859	± 0.196	(c)
	no. yoy	88	21.607	7.3689	±16.794	- 0.2760	0.1036	± 0.236	(4)
	wt.yoy	88	8.1605	1.9808	± 4.514	- 0.1057	0.0278	± 0.063	(d)
Area 3	no. adults	88	-19.900	6.7602	±15.406	- 0.3114	0.0954	± 0.217	(5)
(all habitats)	wt. adults	88	- 8.5802	4.2590	± 9.706	0.1460	0.0601	± 0.137	(e)
	no. yoy	88	10.717	9.0393	±20.601	- 0.1261	0.1275	± 0.291	(6)
	wt. yoy	88	4.4515	2.7348	± 6.233	- 0.0544	0.0386	± 0.088	(f)
Area 4	no. adults	28	- 0.7121	2.5733	± 5.270	0.0031	0.0363	± 0.0743	(7)
(lake)	wt. adults	28	- 2.7545	5.0897	±10.424	0.0188	0.0718	± 0.1471	(g)
	no. yoy	28	- 0.2423	1.8632	± 3.8158	- 0.0094	0.0263	± 0.0539	(8)
	wt. yoy	28	0.0187	0.6675	± 1.3670	- 0.0019	0.0094	± 0.0193	(h)

Area	Abundance index	d.f.	$\hat{\beta}_0$	S.E.	95% C.I.	$\hat{\beta}_1$	S.E.	95% C.I.	
EXCLUDING EMPTY SAMPLES									
Area 1	no. adults	64	- 1.8092	2.8554	± 6.549	0.0368	0.0394	± 0.090	(1)
(all habitats)	wt. adults	64	- 1.4328	2.8884	± 6.625	0.0359	0.0398	± 0.091	(a)
	no. yoy	37	-14.011	37.334	±87.242	0.2426	0.5320	± 1.243	(2)
	wt. yoy	37	- 6.5708	18.223	±42.584	0.1145	0.2597	± 0.607	(b)
Area 2	no. adults	72	-11.644	11.727	±26.855	0.2042	0.1640	± 0.376	(3)
(all habitats)	wt. adults	72	-11.422	7.1724	±16.425	0.1988	0.1003	± 0.230	(c)
	no. yoy	47	13.791	31.649	±31.638	- 0.1485	0.2012	± 0.466	(4)
	wt. yoy	47	6.7514	3.6583	± 8.480	- 0.0818	0.0539	± 0.125	(d)
Area 3	no. adults	69	-20.624	9.2010	±21.079	- 0.3247	0.1279	± 0.293	(5)
(all habitats)	wt. adults	69	- 5.3278	5.7000	±13.059	0.1057	0.0792	± 0.181	(e)
	no yoy	49	- 5.3887	17.020	±39.333	0.1258	0.2495	± 0.577	(6)
	wt. yoy	49	- 0.0430	5.1495	±11.900	0.0151	0.0755	± 0.174	(f)
Area 4	no. adults	23	- 1.1910	2.7969	± 5.761	0.0011	0.0394	± 0.0811	(7)
(lake)	wt. adults	23	- 3.6765	5.6870	±11.766	0.0278	0.0801	± 0.1656	(g)
	no. yoy	13	- 1.8580	3.8379	± 8.290	0.0384	0.0545	± 0.1179	(8)
	wt. yoy	13	- 0.3879	1.3708	± 2.962	0.0099	0.0195	± 0.0420	(h)

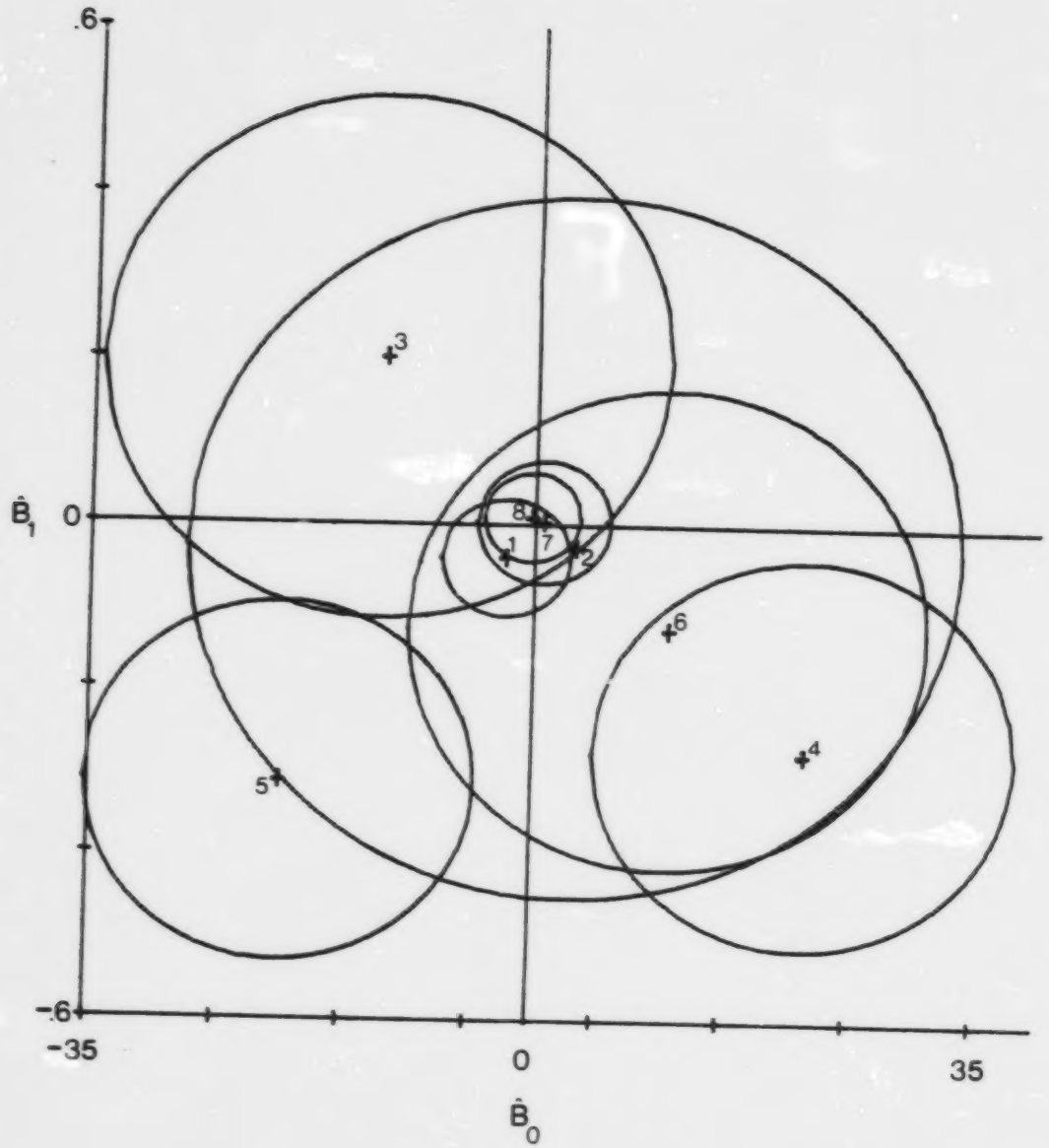

Fig. 38. Confidence ellipses demonstrating effects of sampling areas on the relations of numerical densities of captured adult and juvenile fish and sampled volumes. Empty samples were included.

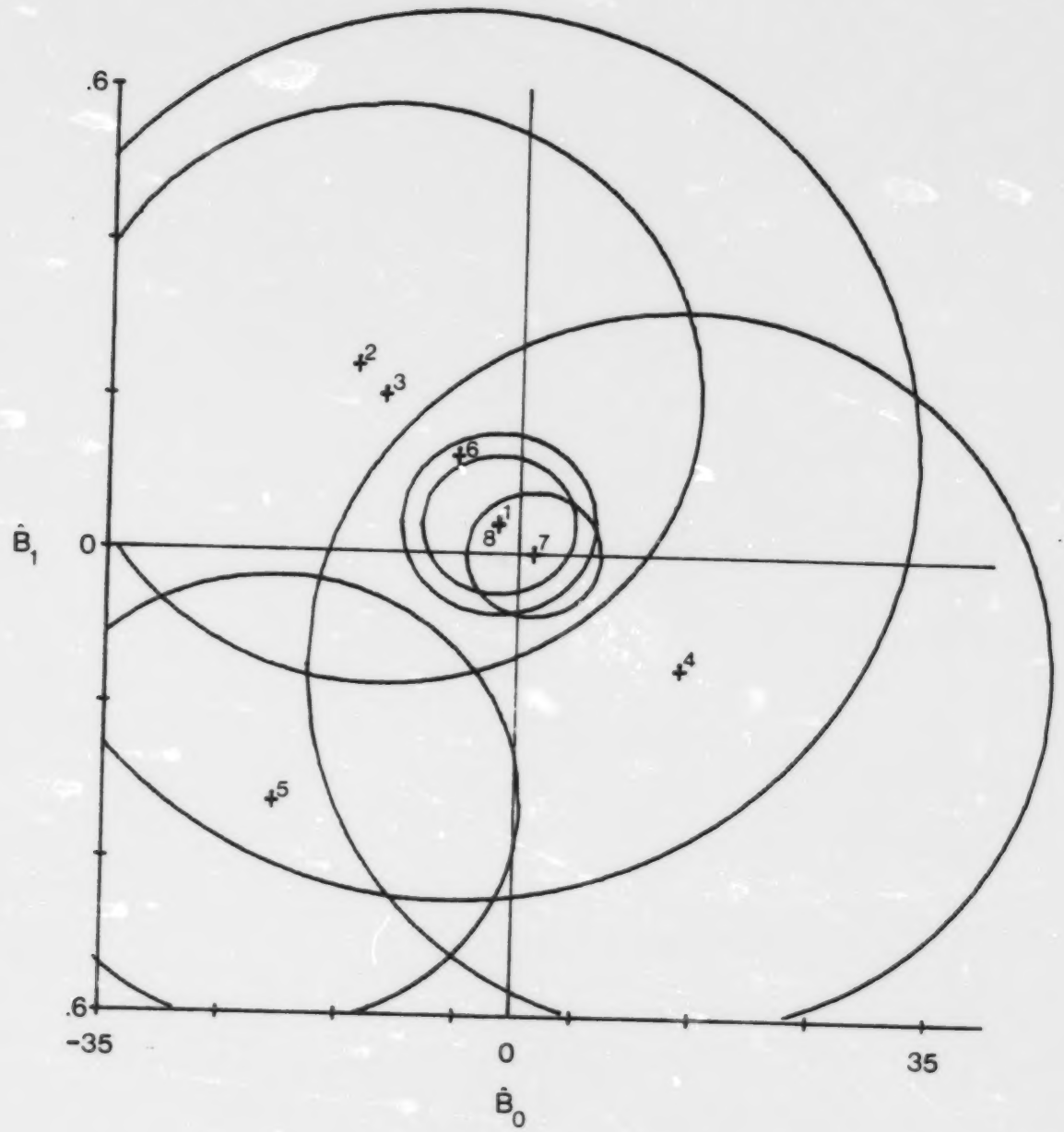

Fig. 39. Confidence ellipses demonstrating effects of sampling areas on the relations of numerical densities of captured adult and juvenile fish and sampled volumes. Empty samples were excluded.

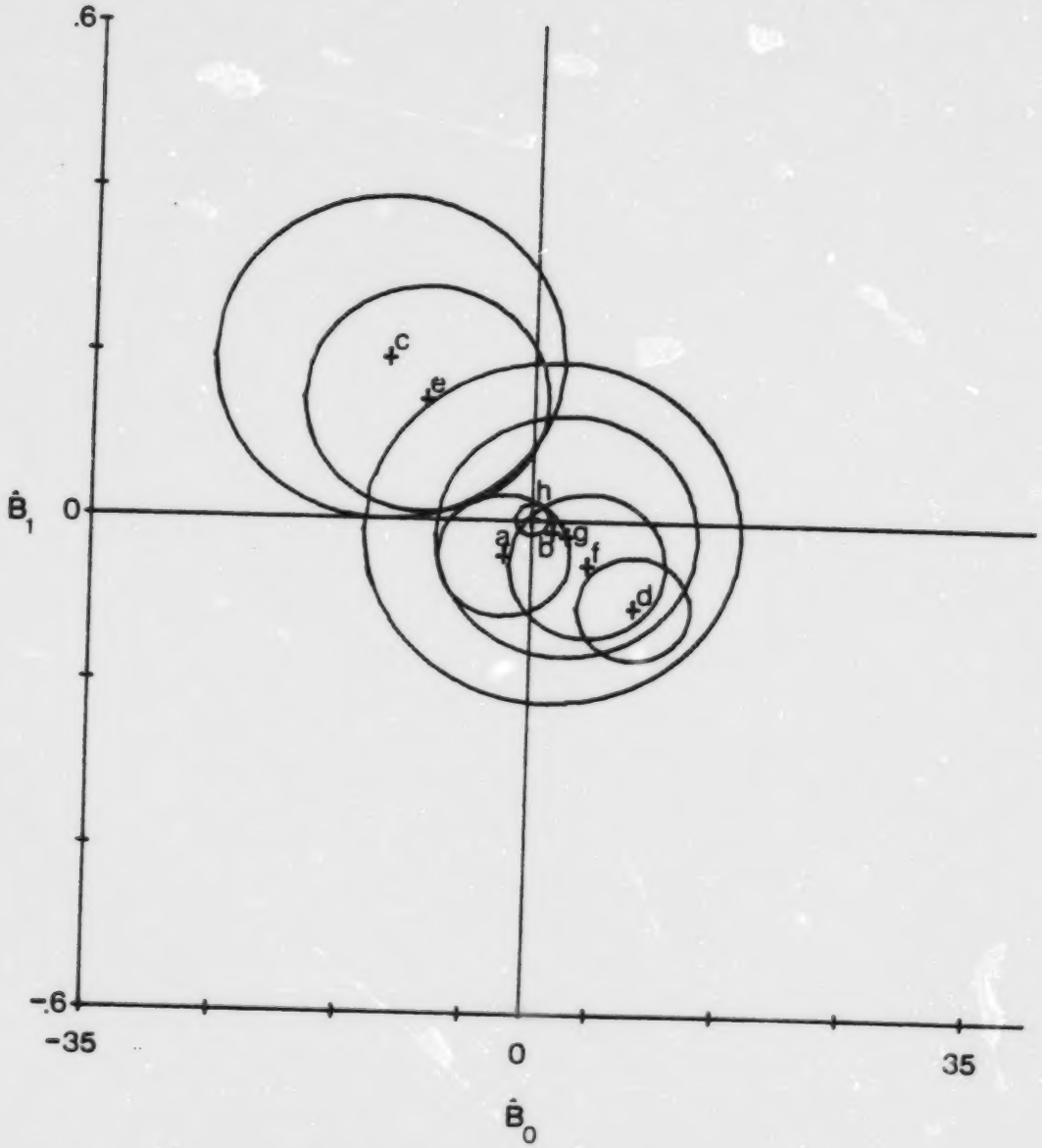

Fig. 40. Confidence ellipses demonstrating effects of sampling areas on the relations of weight densities of captured adult and juvenile fish and sampled volumes. Empty samples were included.

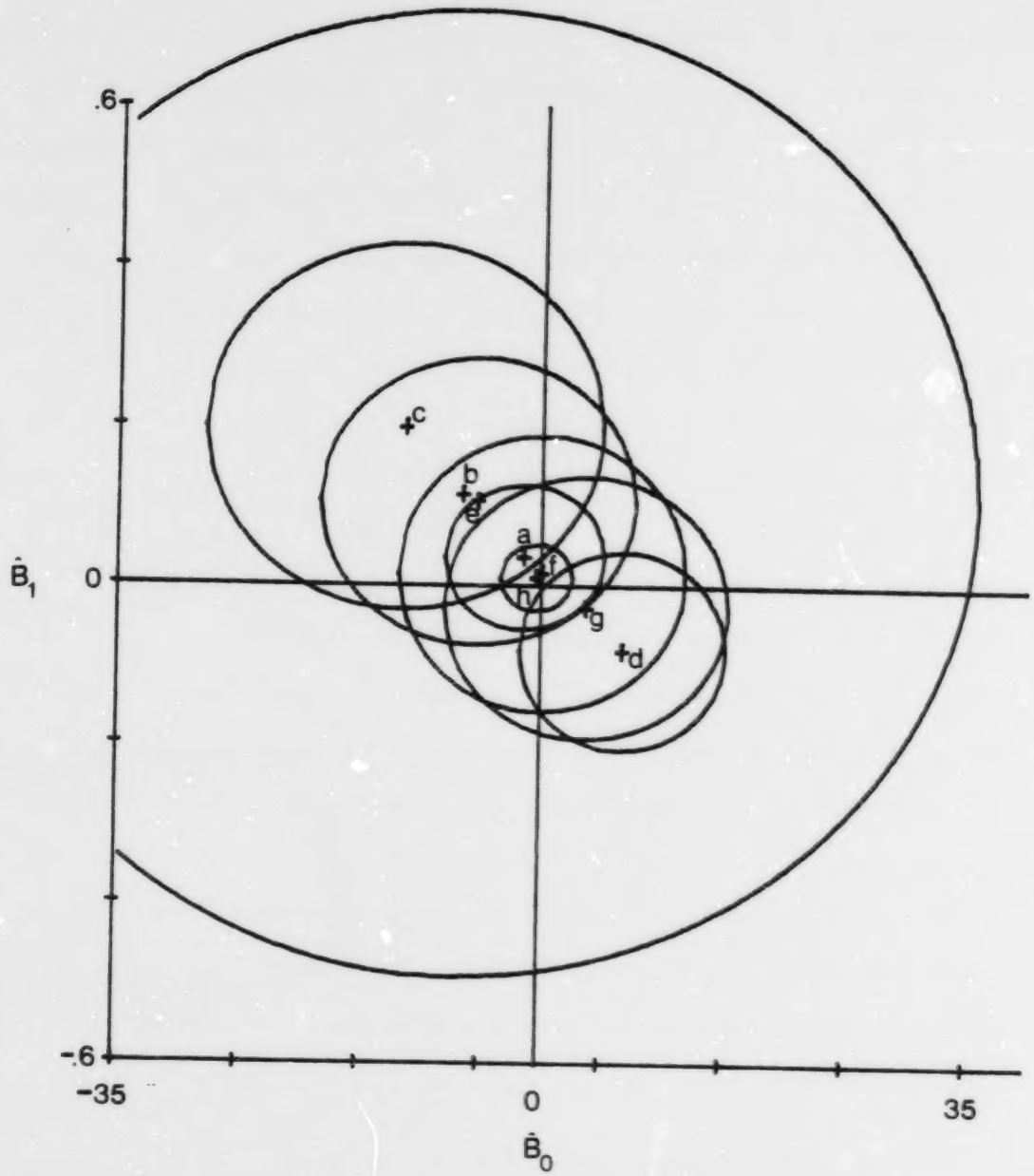

Fig. 41. Confidence ellipses demonstrating effects of sampling areas on the relations of weight densities of captured adult and juvenile fish and sampled volumes. Empty samples were excluded.

concentrations of yoy emerald shiners. During 1984, concentrations of yoy shiners in areas 2 and 3 occurred about 2 weeks earlier than in area 1. (compare Figs. 23 and 27 to Fig. 19). In both years, the late summer peaks of yoy shiners were followed by rapid dispersion and in many cases, yoy shiners began re-concentrating in autumn (Figs. 3-15).

Attempts to determine ages of emerald shiners using both scales and otoliths were not successful. Annuli were visible on all otoliths. Since the majority of fish caught in townets were either yoy, yearlings or two year old fish, difficulty in consistently determining formation of new annuli at otolith edges caused large variations in age estimates. Scales were rejected as reliable ageing sources because most of them were regenerate. Also, we noticed that many live emerald shiners have the annoying habit of shedding a large portion of their scales when they are emptied from townets. This makes it impossible to trace the owner of most sampled scales. Consequently, we resorted to an analysis of length frequency distributions to determine the age structure of the shiner stock. The 1983 length frequency distributions (LFD) using a one mm class interval (Figs. 42, 43) were smoothed using a variety of moving averages. Three point averages produced smooth length frequency distributions (Figs. 44, 45) that were interpreted as follows:

a. One and two year old shiners were caught by townets in period 4.

b. yoy emerald shiners appeared during period 5 and their dominance in the catches increased steadily until the end of the sampling period.

c. From periods 5 to 8, size ranges and modal sizes of yoy shiners increased steadily.

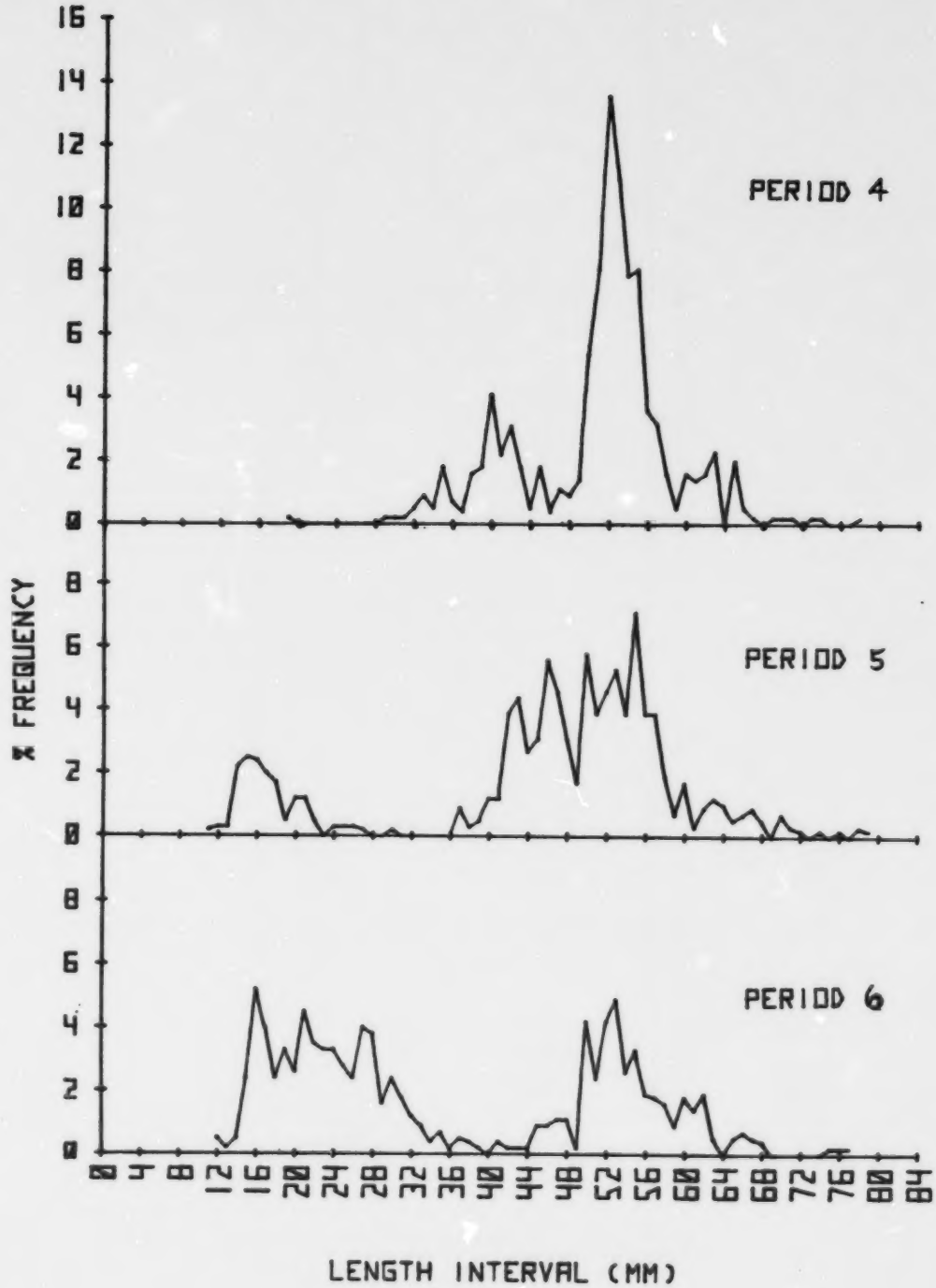

Fig. 42. Length frequency distributions of Red River emerald shiners, 1983.

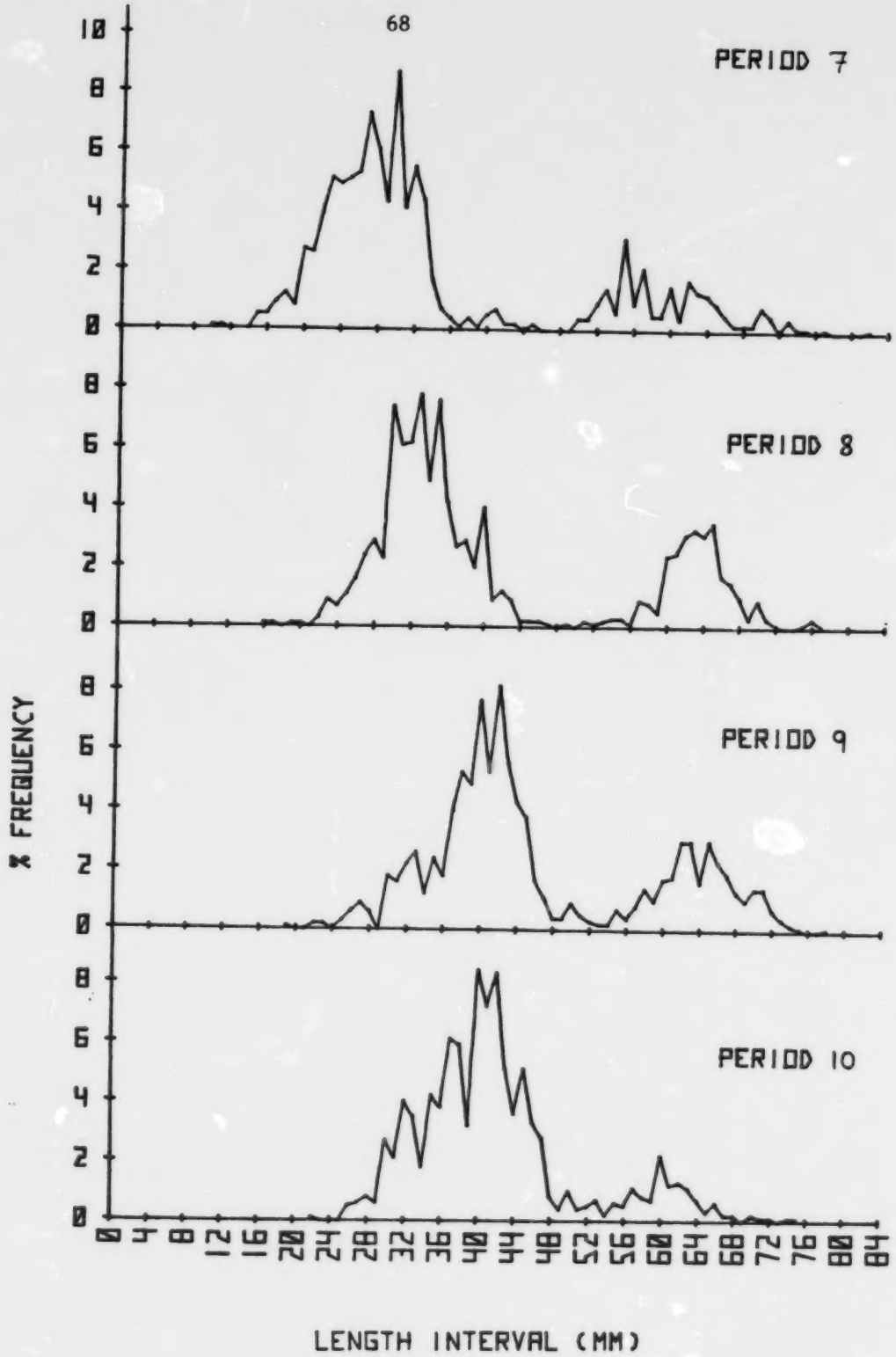

Fig. 43. Length frequency distributions of Red River emerald shiners, 1983.

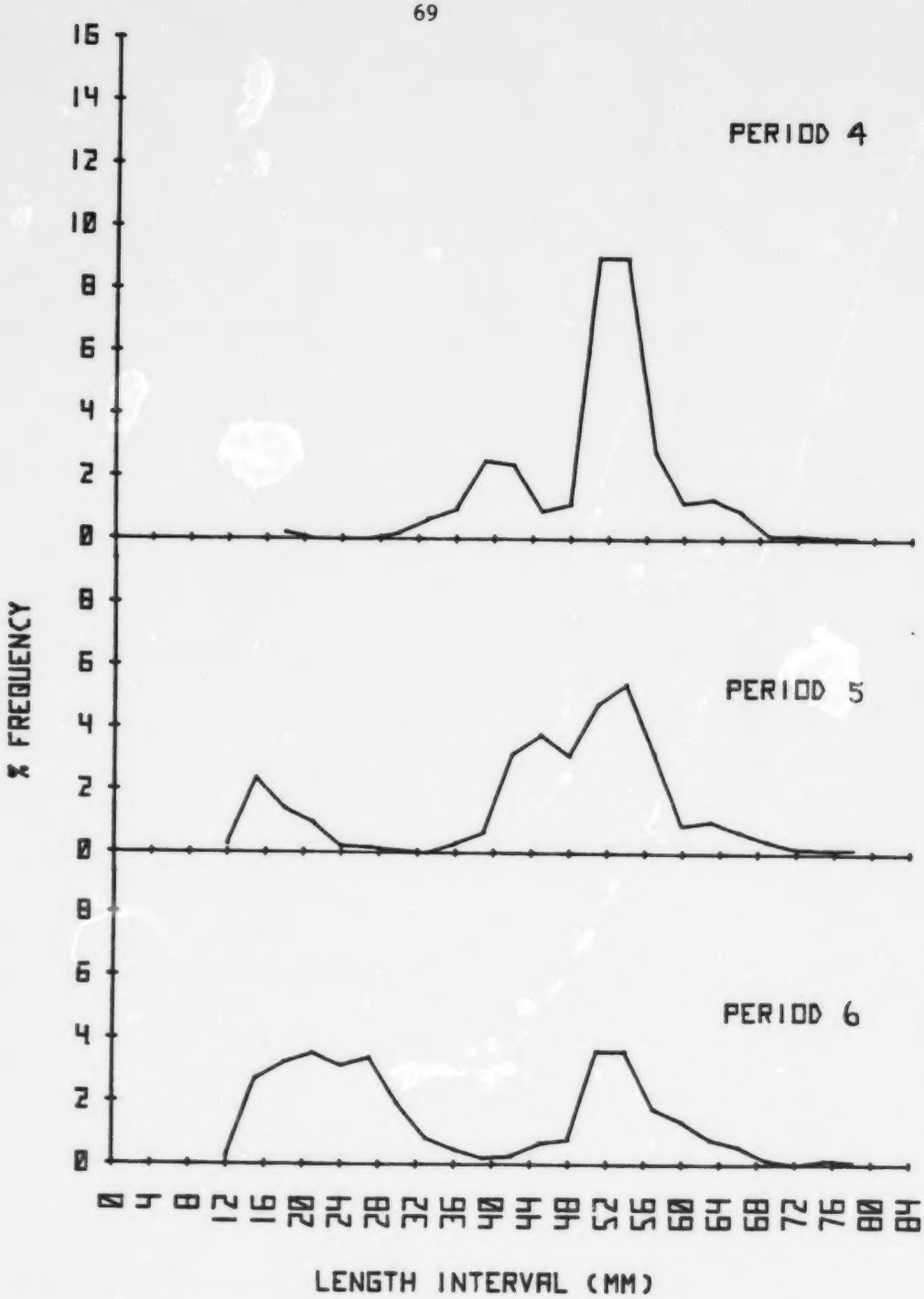

Fig. 44. Smoothed length frequency distributions of Red River emerald shiners, 1983.

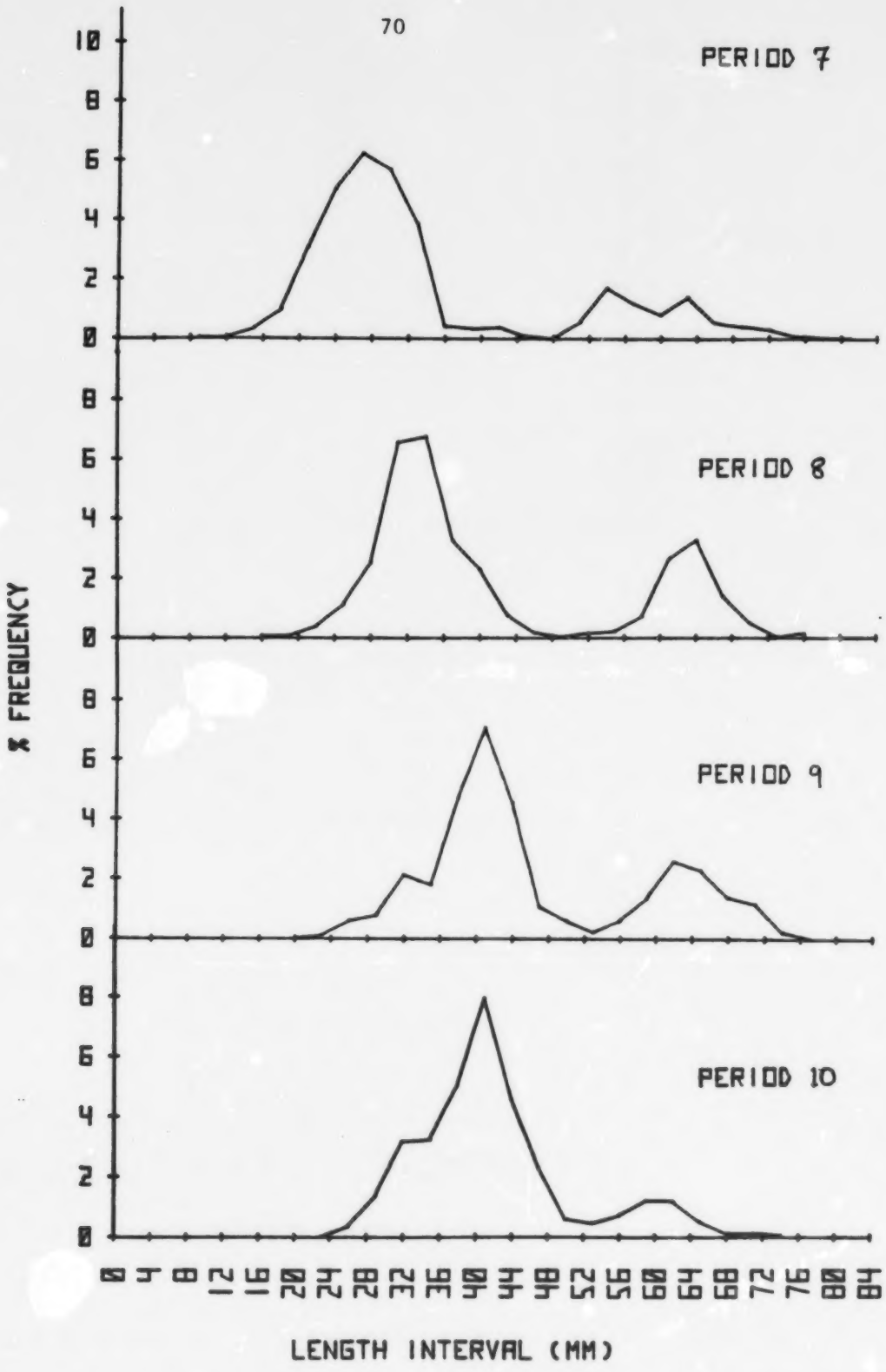

Fig. 45. Smoothed length frequency distributions of Red River emerald shiners, 1983.

d. During periods 9 and 10, modal lengths of juvenile shiners did not increase but a group of small (24-36 mm) shiners was recruited.

e. One year old shiners were present in catches from period 4 to period 7. From period 4 to period 6, modal sizes of 1+ fish increased steadily and their size distribution remained discrete. The fastest growing yoy fish created a bimodal (53 mm and 65 mm) distribution in period 7.

f. The decreasing modal lengths of larger fish caught during periods 8 to 10 indicated continuing recruitment of fast growing yoy fish.

g. The "disappearances" of two year old fish after period 6 and one year old fish after period 7 were probably due to gear selectivity for smaller fish.

Similarly, the 1984 length frequency distributions using a one mm. class interval (Figs. 46-49) were smoothed using three point averages (Figs. 50-52). As in 1983, yoy shiners appeared in sampling period 5 in 1984 and exhibited steadily increasing modal lengths and discrete distributions until period 9. Individual growth rate variations and recruitment of new juveniles created plurimodal size distributions of younger fish in periods 9 and 10. Two year old shiners were present in catches from periods 1 to 6. Rapid and increasingly variable growth of yearlings created the decay in size distributions of one year old fish during periods 3 and 4 (Figs. 50-52).

Seasonal growth curves (Fig. 53) were plotted using the weighted mean lengths listed on Table 4. The length ranges used to derive weighted mean lengths (denoted by parentheses on Table 4) were arbitrarily chosen to coincide with minima in the smoothed length frequency distributions. Thus the weighted mean lengths are subjective in many instances. The largest sampled shiner was 85 mm long.

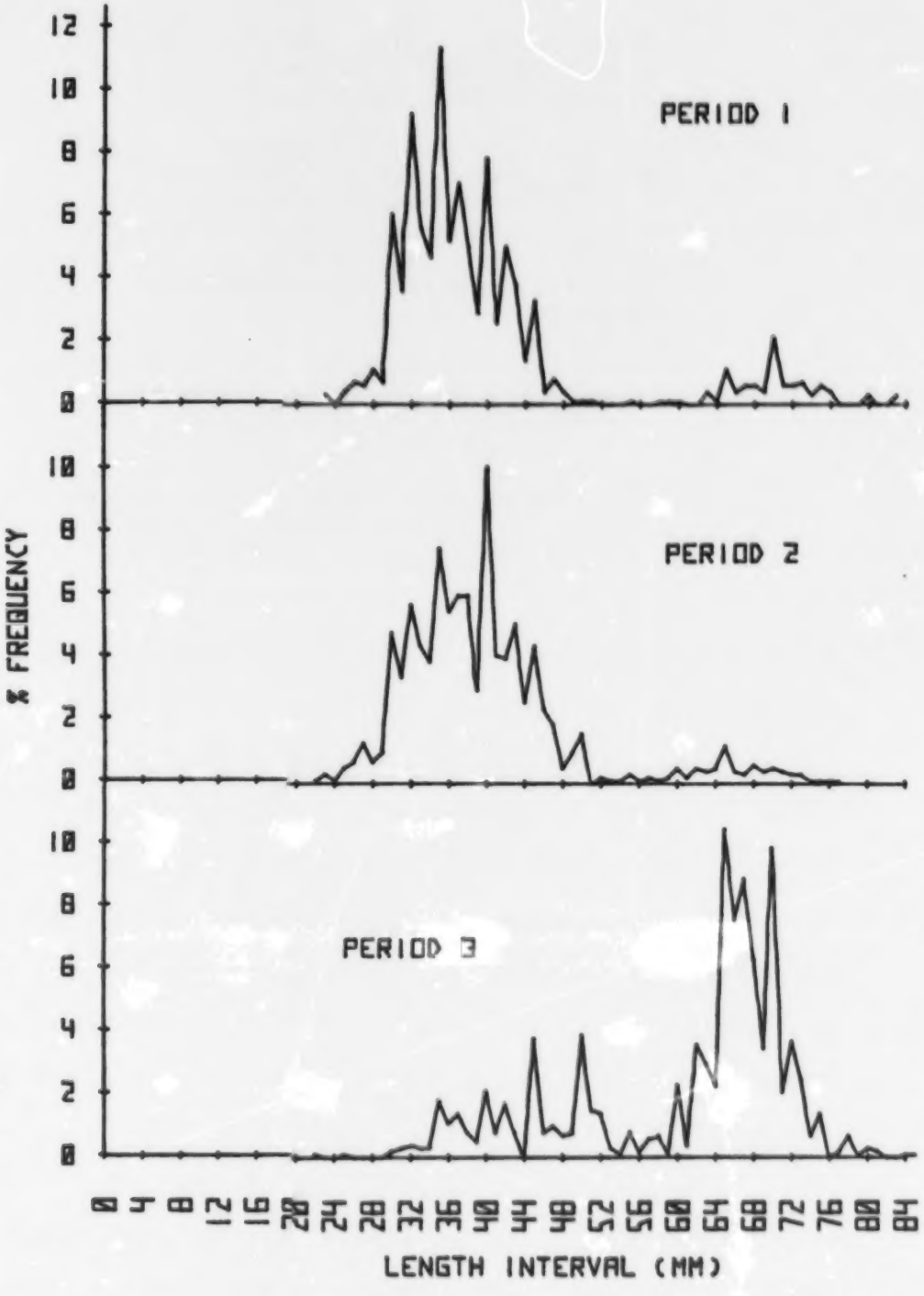

Fig. 46. Length frequency distributions of Red River emerald shiners, 1984.

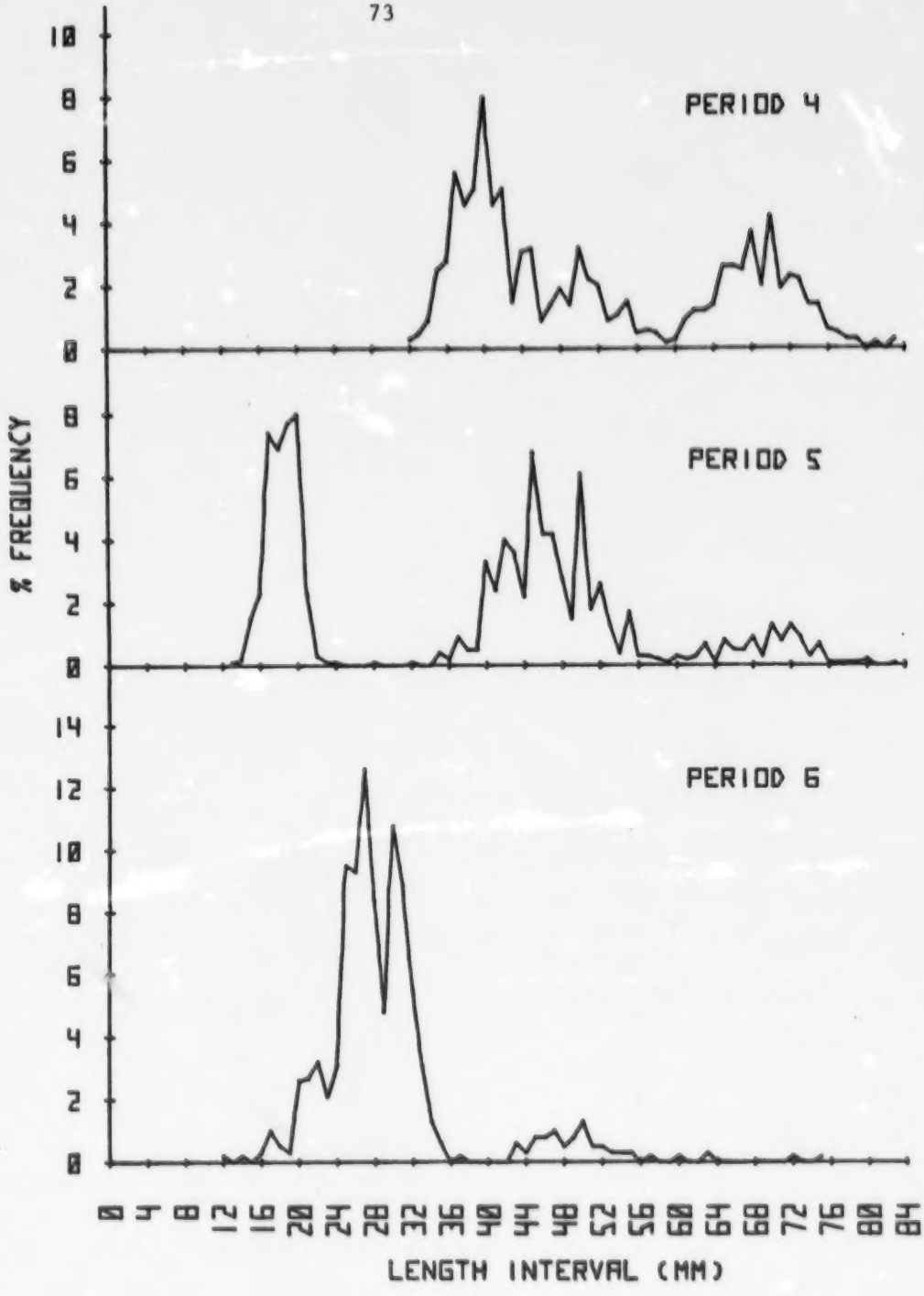

Fig. 47. Length frequency distributions of Red River emerald shiners, 1984.

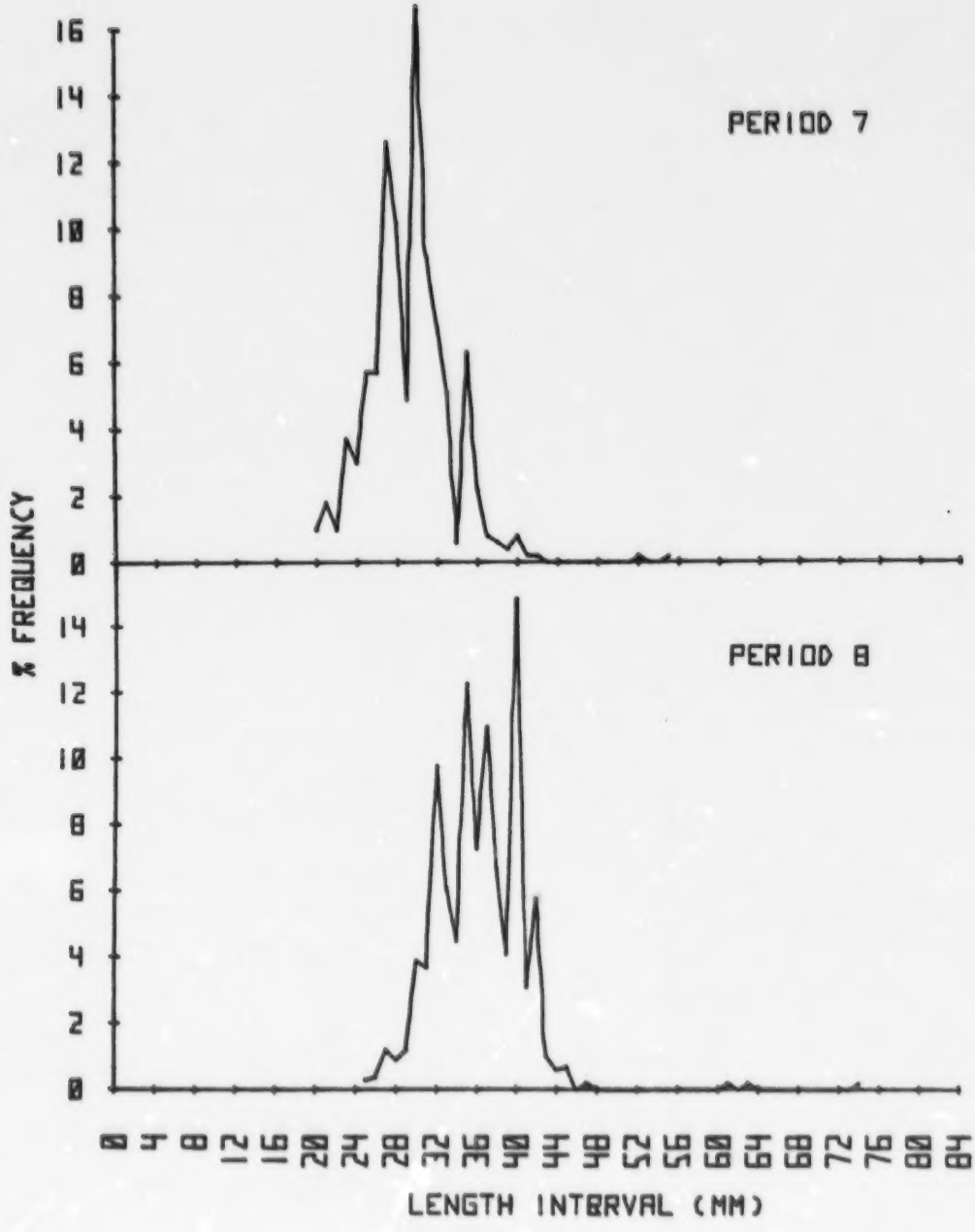

Fig. 48. Length frequency distributions of Red River emerald shiners, 1984.

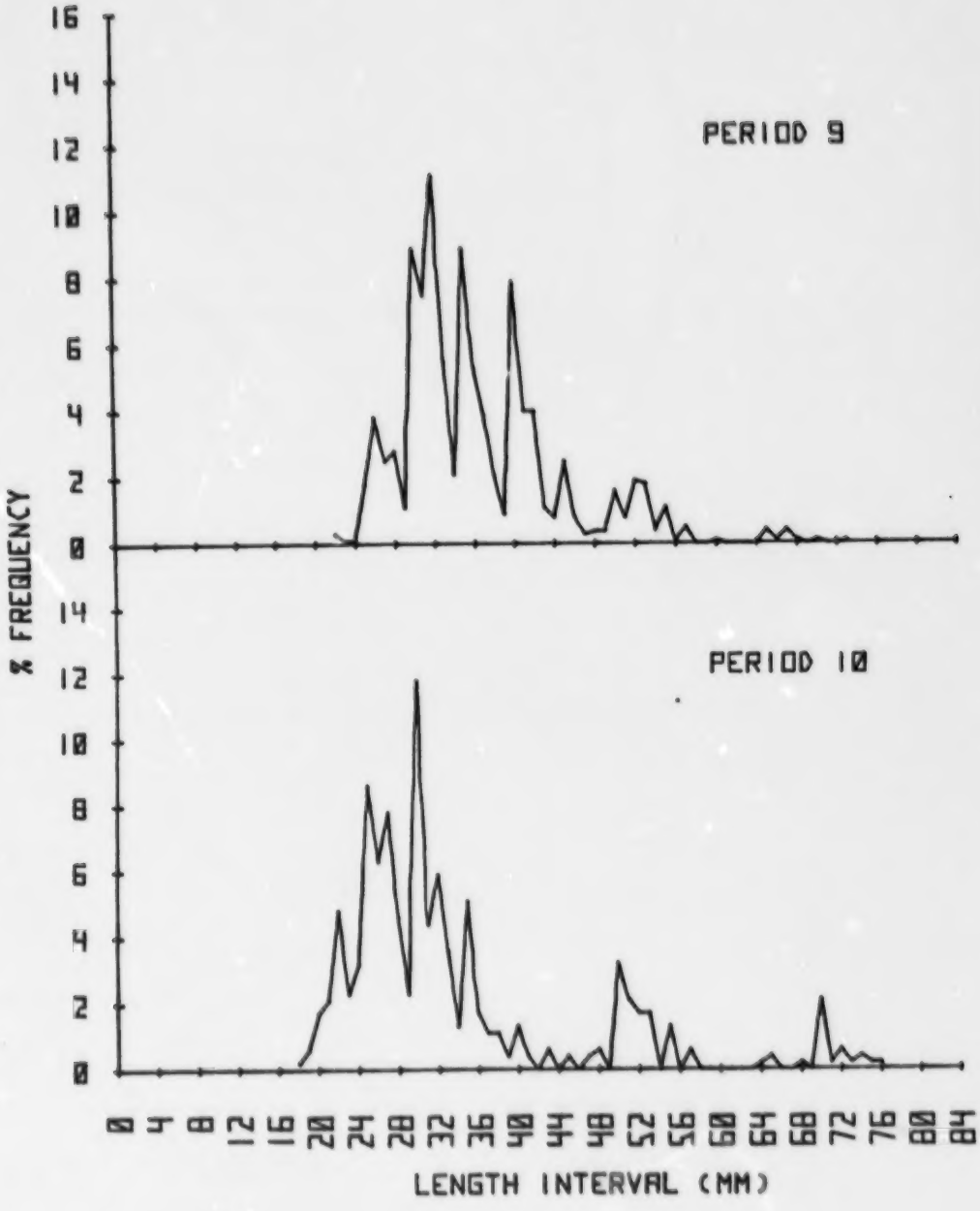

Fig. 49. Length frequency distributions of Red River emerald shiners, 1984.

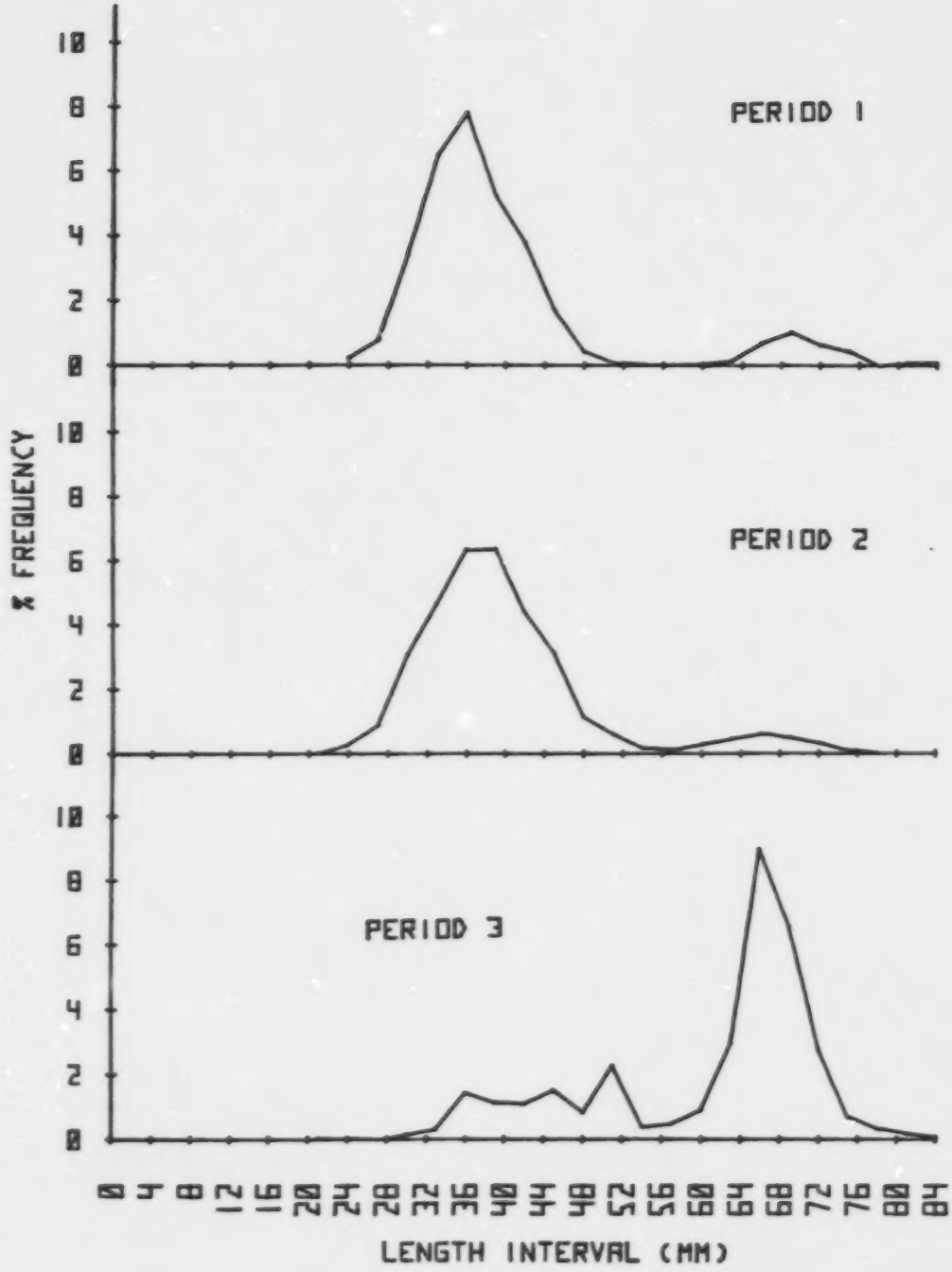

Fig. 50. Smoothed length frequency distributions of Red River emerald shiners, 1984.

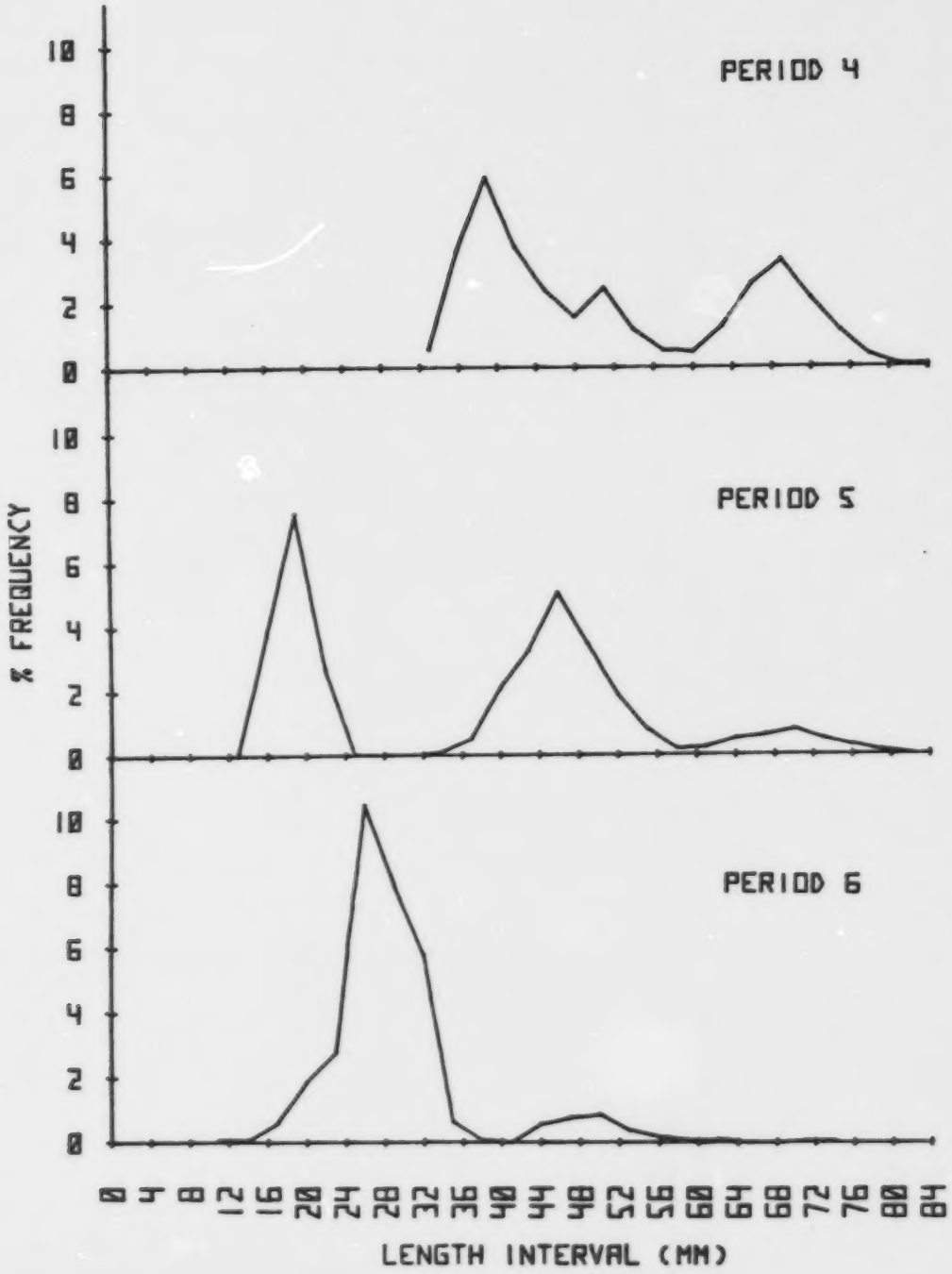

Fig. 51. Smoothed length frequency distributions of Red River emerald shiners, 1984.

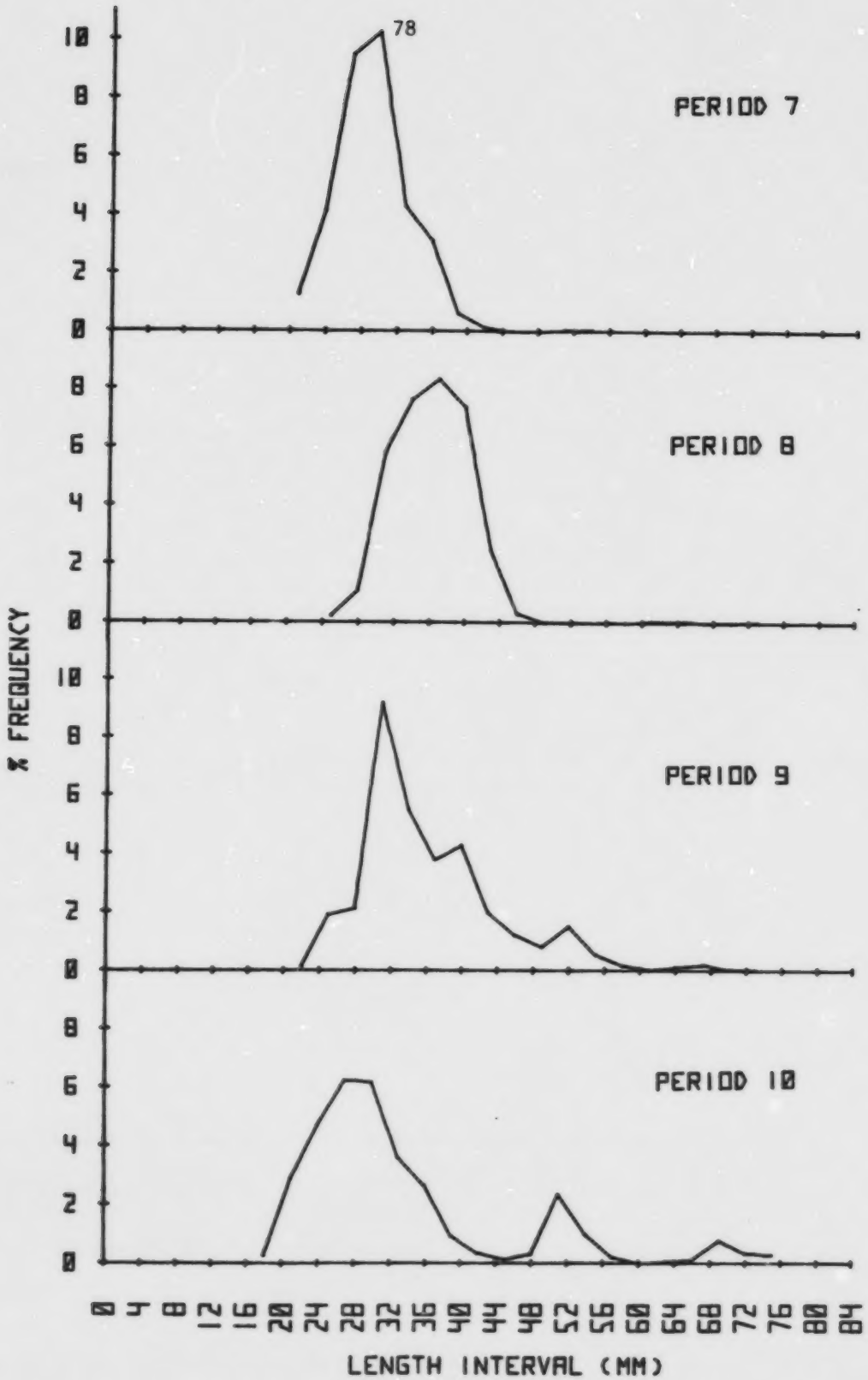

Fig. 52. Smoothed length frequency distributions of Red River emerald shiners, 1984.

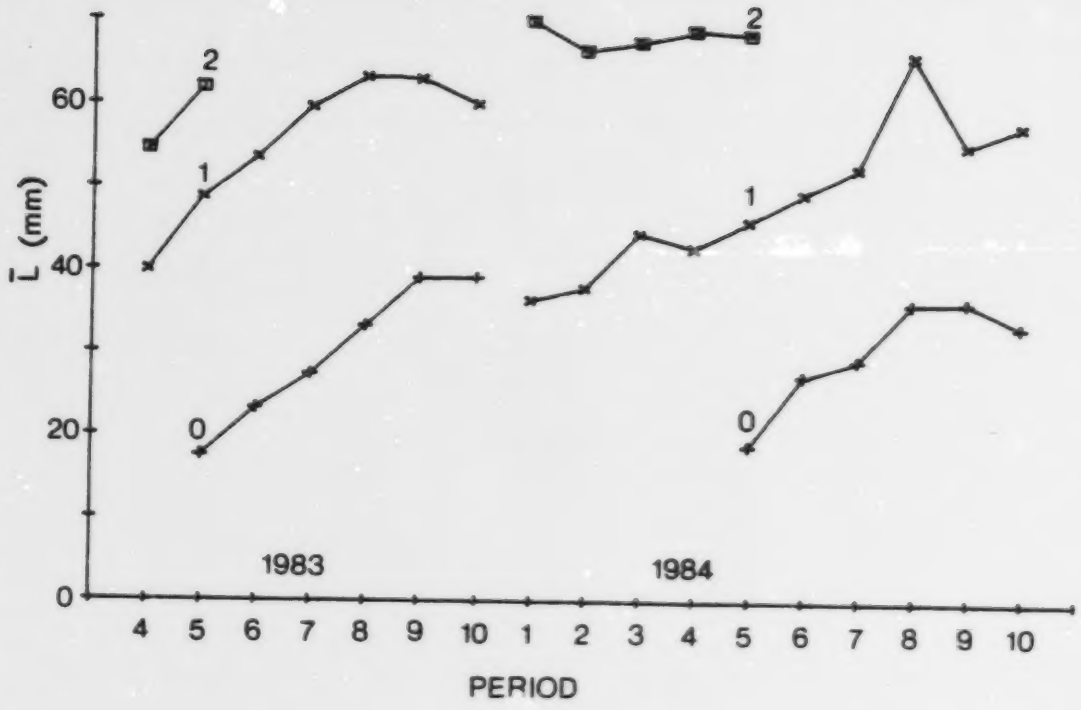

Fig. 53. Temporal changes in weighted mean lengths of yoy, yearling and two year old emerald shiners during 1983 and 1984.

Table 4. Temporal changes in weighted mean lengths (mm) of Red River emerald shiners 1983-1984.*

Sampling period	1983			1984		
	0+	1+	2+	0+	1+	2+
1				-	36.35 (23-54)	69.94 (54-84)
2				-	37.84 (20-54)	66.44 (54-78)
3				-	44.48 (20-54)	67.53 (54-84)
4	—	39.90 (18-45)	54.50 (45-72)	-	42.74 (32-54)	68.94 (54-84)
5	17.47 (9-30)	48.77 (33-54)	61.90 (57-72)	18.77 (12-30)	46.00 (30-54)	68.47 (54-82)
6	23.22 (12-36)	53.51 (39-54)	-	27.27 (10-38	49.39 (38-74)	-
7	27.31 (9-45	59.54 (48-75)	- (20-42)	29.21 (50-55)	52.50	-
8	33.20 (15-45)	63.17 (48-75)	-	36.08 (24-45)	66.00 (60-73)	-
9	39.01 (18-45)	62.92 (48-75)	-	36.31 (21-50)	55.28 (50-73)	—
10	39.07 (21-45)	59.99 (48-75)	-	33.37 (17.50)	57.72 (50-75)	—

* Length ranges used to determine weighted mean lengths are in parentheses.

An examination of temporal changes in GMF length-weight regressions (Table 5) comparing confidence ellipses about plots of slopes versus intercepts indicated that all regressions were identical except the one determined during period 8 (Fig. 54).

The size specific maturity ogive of emerald shiner females (Fig. 55) was transformed by:

$$\log_e \frac{(K-Y_\ell)}{Y_\ell} = a + b \cdot \ell$$

where Y_ℓ = frequency of mature males (%) at length ℓ

K = frequency of mature females in largest size classes = 100%

ℓ = length (mm)

All values less than unity and greater than zero were used (Table 6) in fitting the regression:

$$\log_e \frac{(K-Y_\ell)}{Y_\ell} = 14.18 + 0.217 \cdot \ell$$

$r^2 = 0.794$, d.f. = 20, $F = 77.14$

The mean length of maturity determined from the above regression was 66.98 mm. The equation relating fecundity (no. eggs) and size of females (mm) (Table 7) is:

$$\log_e (\text{no. eggs}) = -7.641 + 3.402 \log_e \text{length (Fig. 56)}$$

$r^2 = 0.527$, d.f. = 14, $F = 15.62$

Table 5. Length-weight relationships of emerald shiners from the Red River, 1983.

Period	Sample size	GMF regression $\log_e$ weight =2 + b·$\log_e$ length	95% C.I. intercept	95% C.I. slope
4	287	Y=-11.180 + 2.919X	±0.3626	±0.0914
5	402	Y=-11.038 + 2.877X	±0.1214	±0.0323
6	423	Y=-11.331 + 2.950X	±0.1928	±0.0525
7	319	Y=-11.055 + 2.933X	±0.2100	± .0582
8	100	Y=-12.133 + 3.207X	±0.5300	±0.1521
9	505	Y=-11.315 + 2.988X	±0.1691	±0.0423
10	400	Y=-11.116 + 2.934X	±0.1689	±0.0445

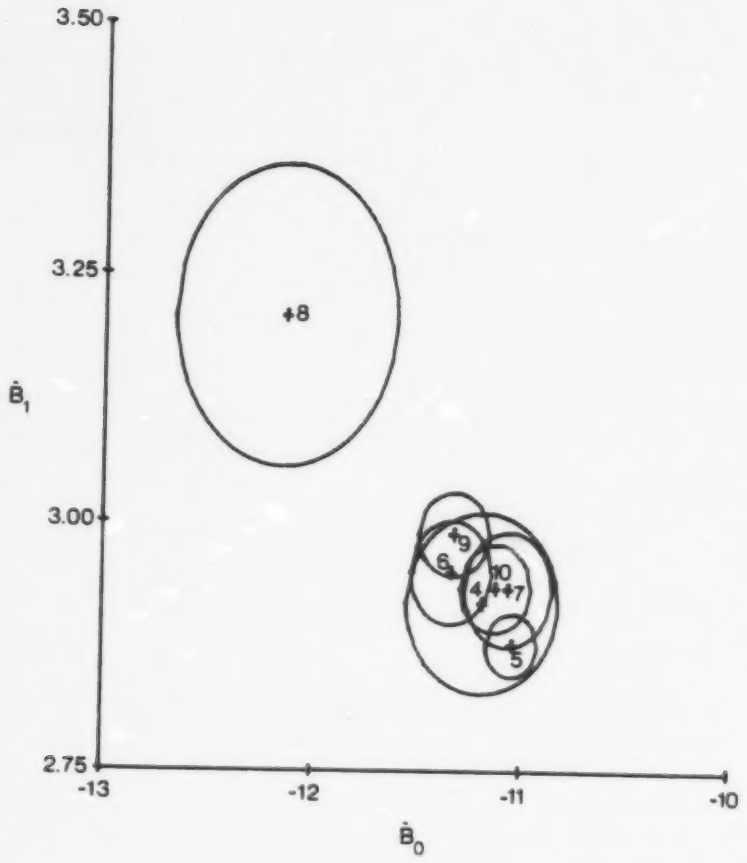

Fig. 54. Confidence ellipses about plots of slopes, $\hat{\beta}_1$ versus intercepts, $\hat{\beta}_0$ of emerald shiner length -weight regressions determined during periods 4 to 10, 1983.

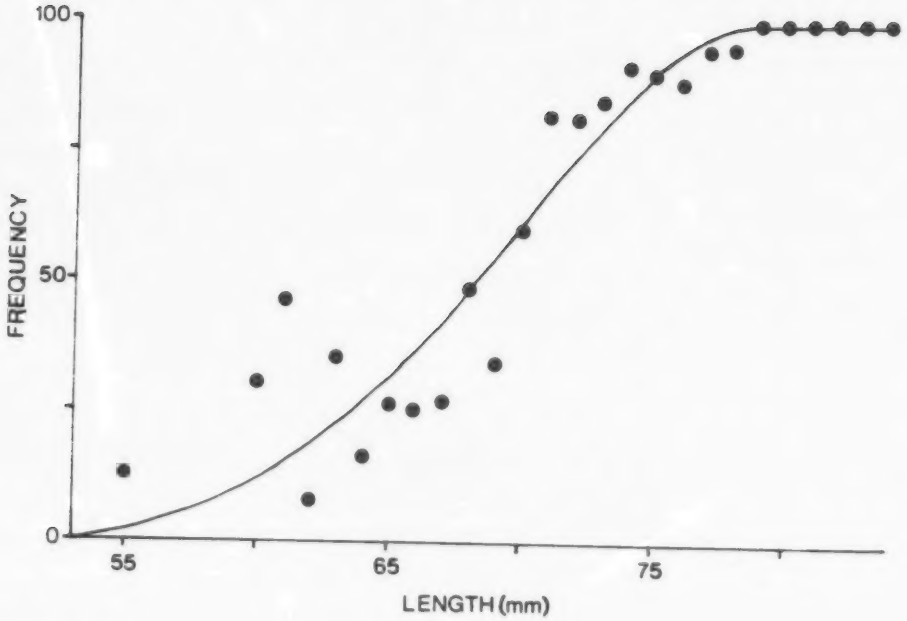

Fig. 55. Size-specific changes in frequencies of mature emerald shiner females.

Table 6. Length-specific frequencies of mature emerald shiners.

Length (mm)	No. fish	No. mature			Frequency of mature fish(%)	
		Males	Females	Total	Males	Females
55	8		1	1	0	12.5
56	1		1	1	0	100.0
57	1		1	1	0	100.0
58	6	1	1	2	16.7	16.7
59	4	1	1	2	25.0	25.0
60	26	2	8	10	7.7	30.8
61	15	2	7	9	13.3	46.7
62	25	7	2	9	28.0	8.0
63	34	8	12	20	23.5	35.3
64	31	12	5	17	38.7	16.1
65	105	36	28	64	34.3	26.7
66	95	38	24	62	40.0	25.3
67	81	36	22	58	44.4	27.2
68	102	24	50	74	23.5	49.0
69	41	16	14	30	39.0	34.1
70	178	31	107	138	17.4	60.1
71	50	2	41	43	40.0	82.0
72	71	6	58	64	8.5	81.7
73	53	2	45	47	3.8	84.9
74	23		21	21	0	91.3
75	41		37	37	0	90.2
76	17	1	15	16	5.9	88.2
77	10		9	9	0	90.0
78	10	1	9	10	10.0	90.0
79	6	0	6	6	0	100.0
80-87	18	0	18	18	0	100.0
Σ	1052	226	543*	769		

* mature sex ratio 2.4 females: 1 male

Table 7. Fecundity of female emerald shiners from the Red River.

Length (mm)	Weight (gm)	No. eggs	No. eggs /gram
60	2.35	522	222.13
61	2.33	481	206.44
63	3.03	860	283.83
65	3.40	499	146.76
66	3.63	924	254.55
67	3.56	887	249.16
68	3.68	937	254.62
69	3.45	514	148.99
70*	3.95	1047	265.06
72	4.99	1849	370.54
73	4.44	1280	288.29
74	4.55	847	186.15
75	4.85	896	184.74
76	4.37	929	212.59
78	4.88	1160	237.70
83	6.46	1975	305.73

* Fish longer than 70 mm were partially spent.

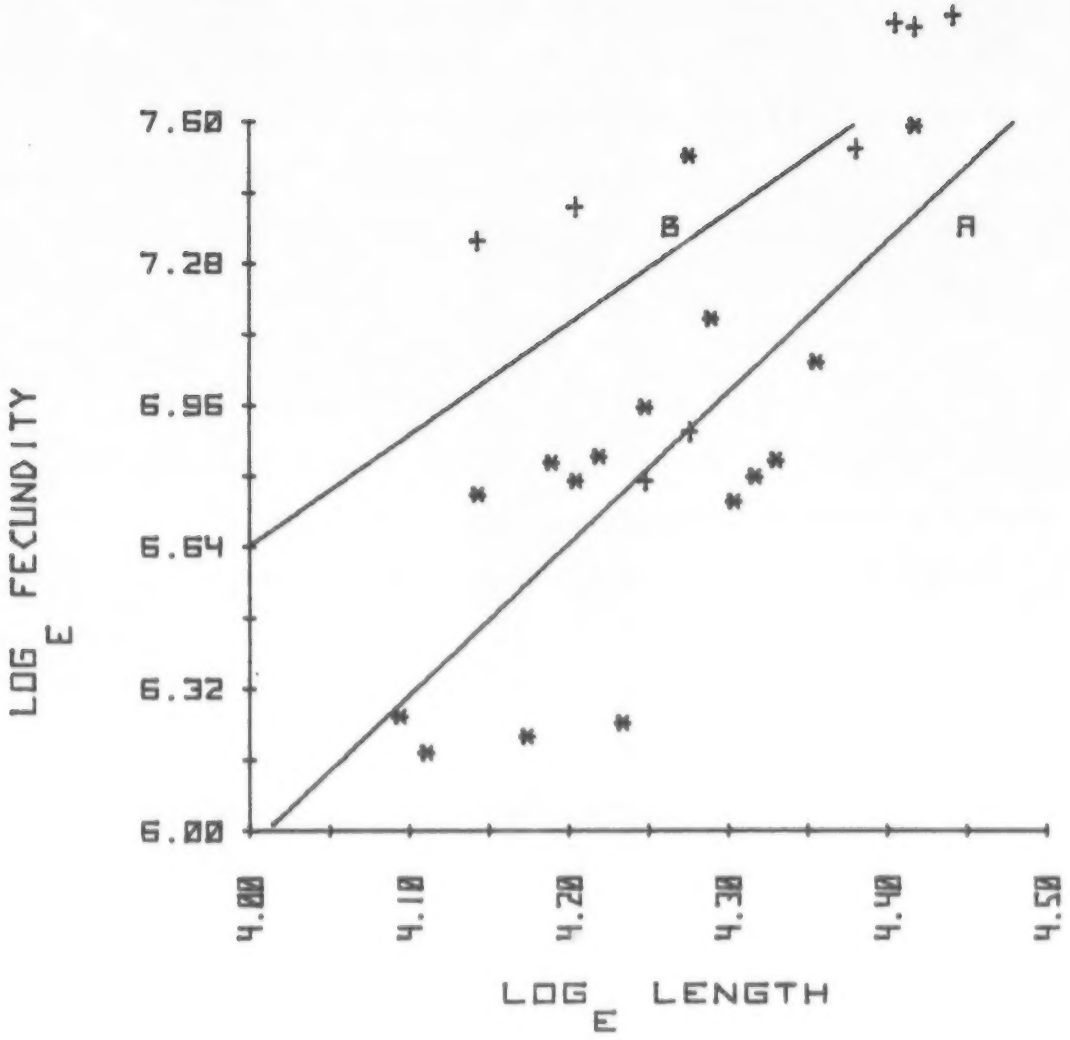

Fig. 56. Regression of fecundity (no. eggs) on body lengths of Red River emerald shiner females (A) and from Flittner (1964)(B).

The durations during which developing and spent gonads were observed overlapped during the period of rapid warming of Red River water (Fig. 57, Table 8). Most spawning probably occurred over a relatively long period in June and early July.

The length frequency distributions of emerald shiners commercially harvested by fishermen employing side rigs included somewhat higher proportions of larger fish than length frequency distributions of shiners caught in front rigs (Fig. 58). However, the mean total number of fish per tub and the mean total weight of fish per tub did not differ between the two types of commercial gear (Table 9). Fishing effort was highest in late May and decreased steadily until September. Catches of emerald shiners were largest in May and June. Catch per unit of effort (CUE) increased from May to early July, decreased during late July and August and increased again in early September (Table 10, Fig. 59). During May and June, fishing effort was dispersed over the entire downstream stretch of the Red River. During July and August, fishermen concentrated their effort in Lake Winnipeg at the river's mouth or in the Selkirk and Lockport areas. During August and September, only the Selkirk and Lockport areas were used (Table 11). Effort ranged from 12.5 days to 91.5 days and CUE ranged from 83.1 tubs/day to 637.4 tubs/per day among the sampled bait fishermen (Table 12). Nine fishermen obtained bait fishing licences for the Red River in 1983. Eight of these fishermen provided catch and effort data at various times and seven of the ten fishermen consistently provided complete data during 1983. Our data indicate that eight fishermen produced 84630 tubs of bait fish from the Red River during 1983. This

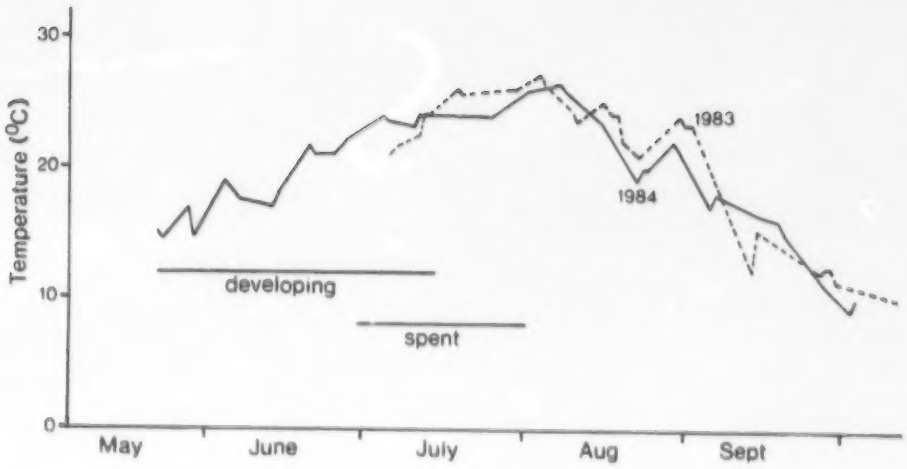

Fig. 57. Durations of emerald shiners exhibiting developing and spent gonads in relation to temporal changes in water temperatures of the Red River.

Table 8. Surface water temperature of the Red River, 1983-84.

Date		Year		Date		Year	
		1983	1984			1983	1984
May	22		15.0	August	22	21.0	19.0
	23		14.5		23		20.0
	28		17.0		24		20.0
	29		14.5		29		22.0
					30	24.0	
June	4		19.0		31	23.5	
	7		17.5				
	13		17.0	September	1	23.5	
	14		18.0		5		17.0
	20		21.5		6		18.0
	21		21.0		12	13.0	
	25		21.0		13	12.0	16.5
	27		22.0		14	15.5	
					15	15.0	
July	4		24.0		18		16.0
	5	21.0	23.5		19		15.0
	6	21.5			26	12.0	
	10		23.0		27	12.5	11.0
	11	22.5	24.0		28	12.5	
	12	24.0			29	11.5	
	13	24.0					
	14	24.5		October	2		9.0
	17		24.0		3		10.0
	18	26.0	24.0		11	10.0	
	19	25.5					
	24		24.0				
	25		24.0				
	28	26.0					
	29	26.0					
August	1		26.0				
	3	27.0					
	4	26.0					
	5	26.0					
	7		26.5				
	8		26.0				
	9	24.5					
	10	23.5					
	15	25.0	23.5				
	17	24.0					
	18	24.0					
	19	22.0					

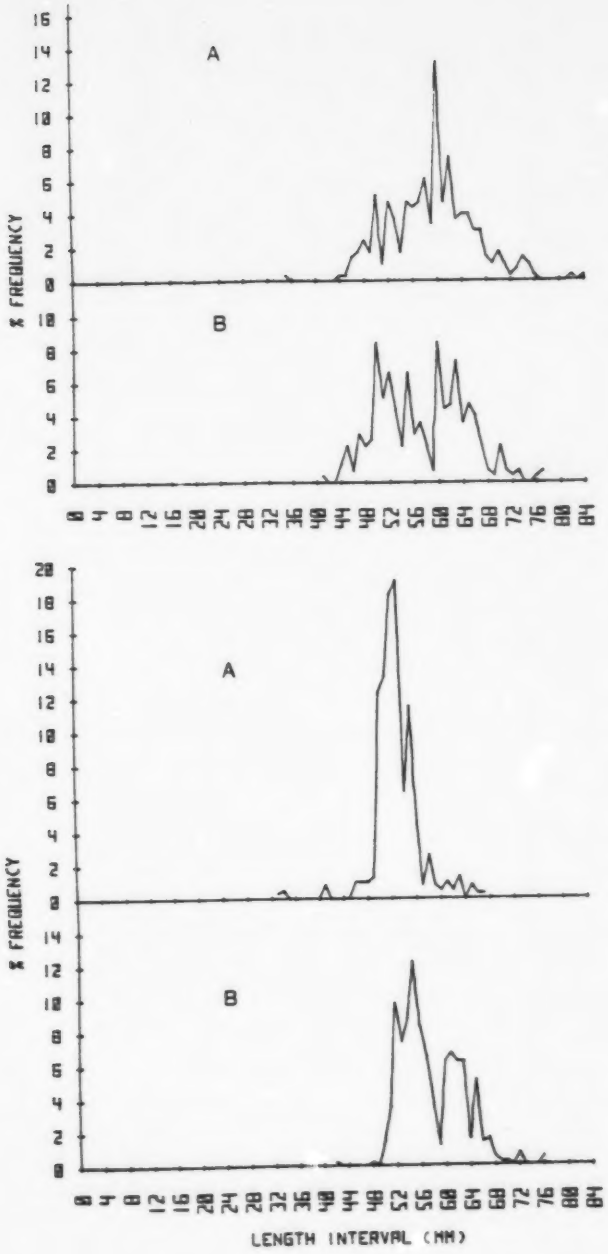

Fig. 58. Length frequency distributions of emerald shiners commercially harvested by front rigs (A) and side rigs (B) in June (upper panel) and July (lower panel).

Table 9. Numbers and weights of emerald shiners in commercially produced tubs, 1983.

Commercial gear type							
Front rig				Side rig			
Date	Total No. fish/tub	Total weight fish/tub(gm)	Mean individual weight(gm)	Date	Total No. fish/tub	Total weight fish/tub(gm)	Mean individual weight(gm)
June 15	94	200.10	2.13	June 15	99	201.74	2.04
	100	205.36	2.05		101	210.00	2.08
	103	211.15	2.05		92	140.00	1.52
July 7	137	263.90	1.93		99	122.09	1.23
	140	266.53	1.90		108	188.81	1.75
	143	279.31	1.95		113	224.17	1.98
Aug. 19	88	178.79	2.03	July 14	106	202.24	1.91
	97	199.69	2.06		104	201.04	1.93
	92	197.11	2.14		106	194.03	1.83
	93	190.32	2.05		102	191.05	1.87
	94	194.28	2.07		—	—	—
Mean	107.36	216.96	2.033		103.00	187.55	1.814
1S.D.	21.374	35.177	.0768		5.793	31.721	.2597

Pooled mean no. fish/tub and 1S.D. = 105.29, 15.764
Pooled mean weight fish/tub and 1S.D. = 202.94, 36.028

Table 10. Temporal changes in commercial fishing effort and yields, 1983.

Period	Total effort (fishermen · days)			Catch (No. tubs)			CUE(No. tubs/day) Weekly	Biweekl
May 2-8	2.5		16	225		2000	90.0	
May 9-15	9.0	31		1595	9900		177.2	196.2
May 16-22	23.5		15	2299		2200	97.8	
May 23-29	18.5			4585			247.8	198.2
May 30-June 6	27.0	(A)		5397	(B)		199.9	
June 7-12	29.5			8933			302.8	253.6
June 13-19	20.5			8730			425.9	
June 20-26	24.5			9050			369.4	395.1
June 27-July 3	15.5			5739			370.3	
July 4-10	5.5			3887			706.7	458.4
July 11-17	6.5			4138			636.6	
July 18 - 24	6.5			2295			353.1	494.8
July 25-31	5.0			871			174.2	
Aug. 1-7	4.5			1010			224.4	198.0
Aug. 8-14	3.5			1597			456.3	
Aug. 15-21	3.5			1091			311.7	384.0
Aug. 22-28	3.0			654			218.0	
Aug. 29-Sept. 4	5.0			770			154.0	178.0
Sept. 5-11	4.0			2891			722.8	
Sept. 12-18	3.0			1951			650.3	691.7
Sept. 19-25	1.0			309			309.0	
Sept. 26-Oct. 2	2.0			1400			700.0	569.7
	Σ=285.5			Σ*=83517				
				+ 1113				
				84630				

* A catch of 1113 tubs was reported without an effort estimate in June.

(A)(B) - During May, one fisherman reported a monthly catch of 9900 tubs and another fisherman reported only biweekly catch and effort data. These data were excluded from the weekly CUE estimates and were included in the biweekly CUE estimates.

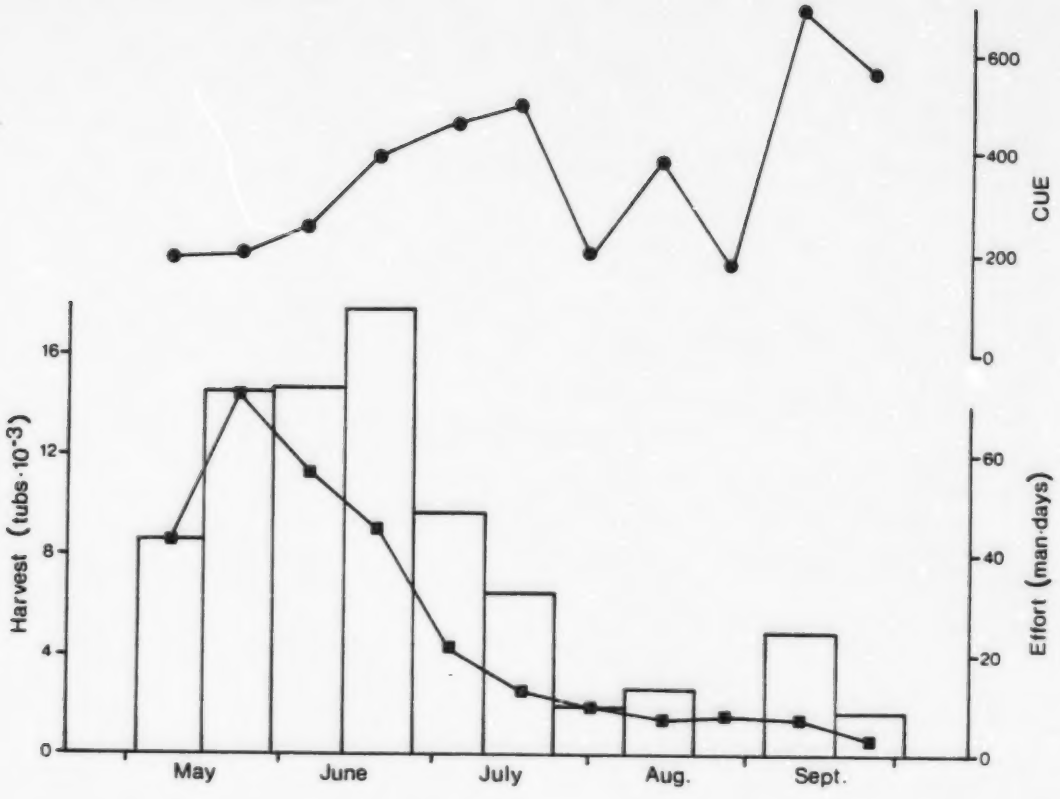

Fig. 59. Temporal changes in emerald shiner harvest (histogram), fishing effort and catch per unit of effort (no. tubs per man per day) on the Red River, 1983.

Table 11. Spatial and temporal changes in the distribution of bait fishing effort (fishermen · days) and yield (No. tubs) on the Red River, 1983.

Period	Reported fishing areas													
	Unreported area		Selkirk & Lockport		Netley		Lake Winnipeg		Selkirk & Netley		Selkirk & Lake		Netley & Lake	
	Effort	Yield	Effort	Yield	Effort	Yield	Effort	Yield	Effort	Yield	Effort	Yield	Effort	Yield
May 2-8	16	2000*	2.5	225										
9-15	15	2200*	1	65	1	1							7	1529
16-22	2	460	6	330	4	77			4.5	11			7	1421
23-29	1.5	7.14	6.5	2035	2.5	123	6	1563	2	150			31	9900*
May 30-June 6			4.5	720	6.5	591			6	1736	3	890	7	1460
June 7-12	5	1330	11	2182	4.5	470			9	4951				
13-19	5	4650	11.5	3704	4	376								
20-26	7	4635	13.5	3361							4	1054		
June 27-July 3			14.5	5039	1	700								
July 4-10			2.5	2484			3	1403						
11-17			0.5	840	2	2400	4	898						
18-24			1.5	1033			5	1262						
25-31			1	50			4	821						
Aug. 1-7			1.5	214			3	796						
8-14			1.5	216			2	1381						
15-21			0.5	147			3	944						
22-28							3	654						
Aug. 29-Sept. 4			1	770							4	0		
Sept. 5-11			4	2891										
12-18			3	1951										
19-25			1	309										
Sept. 26-Oct. 2			2	1400										

* see Table 10

Table 12. Distribution of catch and effort among fishermen who provided complete data sets, 1983.

Fisherman	Catch (No. tubs)	Effort (No. days)	CUE (No. tubs/day)
1	29645	91.5	324.0
2	23624	84	281.2
3	14660	23	637.4
4	6841	42.5	161.0
5	4200	31	135.5
6	2037	24.5	83.1
7	1133	12.5	90.6

catch is equivalent to 17175 kg and 8,910,693 emerald shiners. Fishermen were observed culling about 30% to 50% of their catches. Thus actual harvests are much larger than marketed catches. Catch-effort parabolas (Fig. 60) indicate that the Red River annually produces the largest portion of the provincial bait fish yield (Table 13). Equations for the catch-effort curves on Fig. 60 are:

curve A: $\text{Catch} = -760029.51 + 199716.61\ \text{effort} - 11043.34\ \text{effort}^2$
$r = 0.473$, d.f. = 8, $F = 1.15$

curve B: $\text{Catch} = -278183.76 + 60280.18\ \text{effort} - 2255.05\ \text{effort}^2$
$r = 0.551$, d.f. = 8, $F = 1.74$

curve C: $\text{Catch} = -687927 + 74218.30\ \text{effort} - 1396.61\ \text{effort}^2$
$r = 0.615$, d.f. = 8, $F = 2.44$

The catch and effort data used to derive the above curves are suspect since we estimated that the 1983 Red River yield was 84630 tubs while the fisheries branch's annual records state that 152897 tubs were produced from the Red River in 1983 (Table 13). Data from Table 13 were used to examine temporal changes in CUE from 1970 to 1986 (Fig. 61). Notice the depression in Red River's CUE in 1979. The 1983 Red River CUE would also have been depressed if our catch value (84630 tubs) had been used.

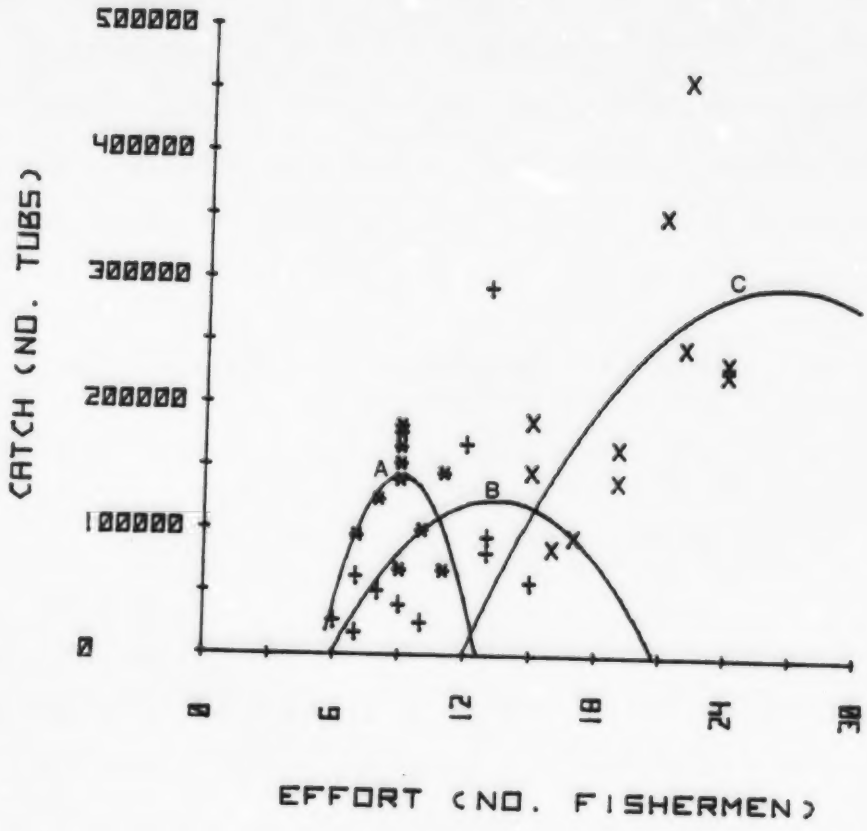

Fig. 60. Catch-effort curves of bait fisheries on the Red River (A), other areas (B) and in the province of Manitoba (C).

Table 13. Annual bait fish catches (No. tubs) and effort (No. fishermen) on Manitoban waters, 1970 - 1986.

Year	Type							
	Frozen shiners						Live fatheads and dace	
	Location							
	Red River		Others areas		Provincial			
	Catch	Effort	Catch	Effort	Catch	Effort	Catch	Effort
1970	68133	9	17835	7	85968	16	40800	2
1971	67619	11	27350	6	94969	17	73596	2
1973	99559	10	40144	9	139701	19	204000	2
1976	139731	9	26138	10	165869	19	352800	3
1979	145208	11	81759	13	226967	24	462600	2
1981	124070	8	62727	7	186797	15	142800	1
1982	95280	7	51097	8	146377	15	331920	3
1983	152897	9	94436	13	247333	22	382836	4
1984	177361	9	58226	15	235587	24	378240	4
1985	183000	9	168645	12	351645	21	328752	4
1986	166412	9	293201	13	459613	22	462000	4

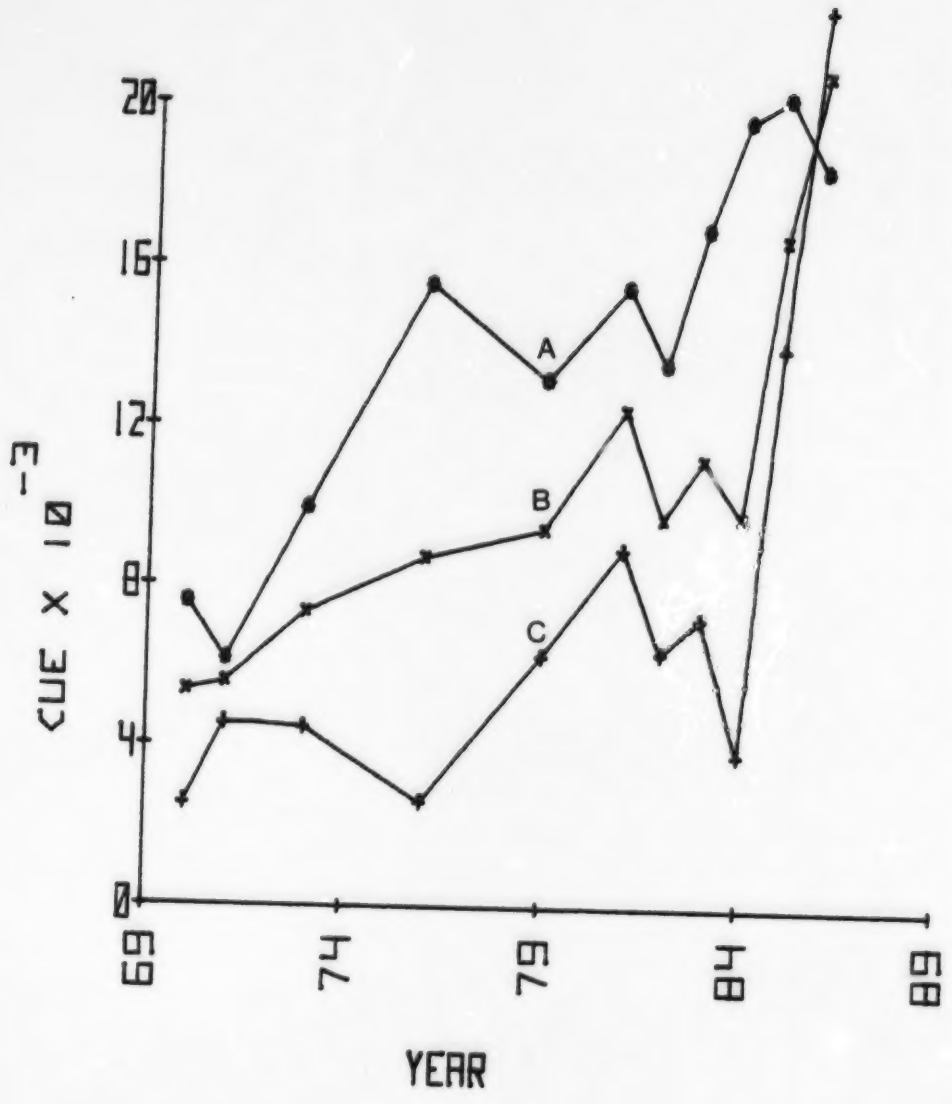

Fig. 61. Annual changes in catch per unit of effort (no. tubs per fisherman) on the Red River (A), in other areas (B) and in the province of Manitoba (C).

DISCUSSION

Employing confidence ellipses about plots of intercepts versus slopes of regressions of abundance indices on sampled volumes is a useful method for determining effects of habitat t pes and sampling areas. This method circumvents interpreting the results of a multitude of ANCOVA's. The use of confidence ellipses in determining whether or not slopes and intercepts are significantly different between habitats or sampling areas is not advocated since confidence ellipses are determined from the t distribution while ANCOVA uses the F distribution.

It is important to consider the effects of "empty" tows when calculating a simple abundance index. For example, if 500 fish are caught in 50 standardized tows, the resulting simple abundance index is 10 fish/tow. However, if 25 of the tows did not catch any fish, one could argue that the abundance index is really 20 fish/tow. High proportions of empty tows may be eliminated by changing sampling methods in some instances. In this study, exclusion of these "empty" samples created larger confidence ellipses than those resulting from inclusion of empty samples. These enlargements were due to decreasing degrees of freedom and subsequently larger $t_{\alpha/2}$ values used in calculating the confidence intervals.

It is also important to consider the relative utility of different types of abundance indices when comparing habitats or areas. In this study, numbers of fish/m^3 among habitats cannot be compared directly in many cases because regressions of number of fish on sampled

volume differs among habitats. This difference implies that the numerical density index (which is a ratio) is not constant over the range of sampled volumes and sampling periods. Using weight of fish/m^3 as an abundance index when comparing areas or habitats is preferable because this index has a lower variance (smaller confidence ellipses) and the confidence ellipses are highly clustered. This implies that the weight of fish/m^3 ratio changes over sampled volumes in different habitats in a similar fashion. Since ratios behave erratically in a statistical sense, it is important to examine whether or not the ratio's numerator is constant over the range of the denominator values. If the numerator and denominator are related in a simple curvilinear fashion, appropriate transformations can be easily applied. Creating an appropriate transformation becomes much more difficult when the numerator is not monotonically related to the denominator.

The weight index was less variable than the numerical index among sampling areas and habitats because the sampling efficiency of the townet is related to the total mass of sampled fish and not by total numbers.

Notice that abundances of fish determined in 1983 were not compared to 1984 abundances. Annual changes in a simple abundance index (mean number of fish/tow) reflect real changes in a stock, within survey sampling variations and changing catchability over time. Using the simple mean catch per tow and its variance to compare year-to-year changes is erroneous since the within survey variance does not account for changes in catchability. Pennington (1986) constructed an abundance index that accounts for catchability changes.

In this study, we determined that emerald shiners were most abundant in the near shore habitats of sampling areas 2 and 3 which correspond to the Netley Creek area exploited by the commercial bait fishermen (Table 11). However, the bait fishermen used the less productive Selkirk-Lockport and Lake winnipeg areas more than the Netley Creek area. Two possible reasons for this behaviour are:

a. Perhaps a larger proportion of commercial catches in the Selkirk-Lockport and Lake Winnipeg areas are composed of larger fish. This is an important factor since fishermen cull small emerald shiners. Small shiners are considered to be less effective bait and are more difficult to retain on hooks than larger shiners. Also decreasing culling time ensures a higher quality of marketed bait since it is important to freeze the shiners quickly.

b. It is physically easier to fish in the Selkirk-Lockport and Lake Winnipeg areas because the bottoms of these areas are smoother and less debris and fewer damaging submerged logs are encountered.

The rapid "disappearance" of riverine adult emerald shiners during late spring was not accompanied by increased catches of adults in Lake Winnipeg. It is hypothesized that they moved into the marshes adjacent to sampling areas 2 and 3 to spawn. The low abundance of juvenile emerald shiners during the summer was followed by a large and rapid increase of juveniles caught in autumn. It is hypothesized that

most of the yoy shiners use the marshes for feeding and avoiding predation by large fish in the river channels during the summer months. Primary and secondary productivity in the marshes are much higher than in the river channels. Newly hatched yoy shiners feed primarily on algae and change to feeding on zooplankton as they grow older (Fuchs 1966).

Over a long period (1970-1986), CUE values in the Red River bait fishery have increased dramatically (Fig. 61). This increase is related to increases in commercial exploitation of Lake Winnipeg's percid stocks (Lysack 1986) since shiners are probably the major prey of walleyes, saugers and perch. Kristofferson (1985) demonstrated an inverse (and slightly lagging) relationship between trawl catches of juvenile percids and shiners. Depression of shiner catches occurs 1-2 years after large percid cohorts are produced. This predator prey interaction is probably responsible for the 1979 depression in the bait fish CUE (Fig. 61).

It is recommended that:

a. If any future studies of Red River emerald shiners are undertaken, they should include an examination of shiner activities in the marshes.

b. Catch and effort estimates should be refined by ensuring that catches from specific areas in the province and effort in terms of fisherman . days are accurately reported each year.

c. The bait fishing "block" system should be evaluated because bait fishermen do not (and should not be required to) subscribe to the present block boundaries.

d. It is important that vegetated areas of the Red River's shores should not be destroyed to provide improved access for boaters, anglers and other users since these areas provide shelter and food for shiners. It is even more important to evaluate (in economic terms) the contribution of the adjacent marshes to shiner production.

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